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The Chemical Composition of Leaves and Whole Plant as an Indicator of the Range of Available Nutrients for Selective Grazing by Cattle

C. D. Juko and R. M. Bredon

Animal Health Research Centre, Entebbe, Uganda

Grasses in the early stages of growth are mainly leafy, and if eaten by animals the whole plant is grazed uniformly. As the grass grows and the stems develop, the chemical composition of various parts of the plant changes.

The chemical analysis of grasses does not show a complete index of their nutritive values. Stapledon (1927) gives an excellent review of the problem and he emphasizes the influence of different parts of the grass and of the degree of maturity of the plant, on the nutrition of the animals. It was shown by Osvald (1919) that at the hay stage of maturity, the leaves show a higher content of proteins and ash than stems, while the latter are higher in crude fibre. Fagan and Trefor-Jones (1924) confirmed these results and have shown that the difference in the percentage of proteins between stems and leaves throughout the growing period is between 8 and 15 per cent. They found that among the British grasses perennial rye-grass, cocksfoot and timothy always showed very pronounced differences in the percentages of proteins between leaves and stems. The conclusion reached by Stapledon (1927) based on the findings of these workers was that the difference in the amounts of proteins in leaves and stems within the same species is greater than that between the leaves of different species.

If the animals were grazing equally both stems and leaves without selection, the difference between the chemical compositions would not matter; but it was shown by workers of the Welsh Plant Breeding Station, Aberystwyth (1927) that sheep grazed leaves more freely than stems. Fagan (1929) went further and stated that sheep show an instinctive preference for the leafy portion of the grass over the stems. He also found that cattle exercise a certain amount of selection, although not to the same extent as sheep. It was observed by Johnstone-Wallace (1937) that the leaves appear to be consumed by cattle in preference to the stems. Johnstone-Wallace and Kennedy (1944) made further observations and found that cattle select the leafy herbage at an immature stage of growth (4 to 5 in. in height) in preference to more mature herbage.

Information on the selection of grazing by sheep has increased in recent years due to the development of a new technique using an oesophageal fistula by Torell (1954). Heady and Torell (1959) found that sheep were showing preference for different plants and different parts of plants

depending on the season of the year and that preference was not related to the height of the plant.

For ungrazed pasture, using fistulated sheep, WEIR and TORELL (1959) found that sheep selected herbage containing 4·1 per cent more protein and 3·5 per cent less crude fibre than found in hand-clipped herbage.

For cattle much less is known about selection of food and even less about quantitative selectivity. Stapledon states that cattle moved from one vegetation to another during the day to obtain a balance between nutrients. Some indication is given by HARDISON *et al.* (1954) who found from the results of their 63 trials that the diet actually consumed by grazing cattle contained 23 per cent more crude proteins, 37·3 per cent more fat, 25·6 per cent more ash and 16·8 per cent less crude fibre than the diet as represented by clipped samples for chemical analysis. These data cannot be accepted as absolute because of various factors which affect selectivity as shown by STAPLEDON (1934), by HANCOCK (1950) and by RAYMOND *et al.* (1956).

The discussion on this subject which took place during the Seventh International Grassland Congress (1956) made clear that the chemical composition of the whole plant, as clipped for chemical analysis, is not sufficient to determine the economical value of grasses.

This paper aims to show the chemical composition of leaves and that of the whole plants of some Uganda grasses and therefore to show the nutrients which can be available to animals at various stages of the growth of grass and to what extent the changes in nutrients are affected by the degree of maturity of grass as influenced by climatic conditions.

MATERIALS AND METHODS

The sampling of grasses was carried out within a period of a few days on three experimental stations in Uganda. Samples of three to four pounds in weight were collected and divided into two parts. One part was used for determination of the chemical composition of the whole plant. In the other half of the sample the leaves were separated from the stems by holding the stems one inch below the point where the leaf joins the stem and pulling the leaf downwards. The species of grasses which were investigated were: *Brachiaria brizantha*, *Chloris gayana*, *Cenchrus ciliaris*, *Hyparrhenia rufa*, *Melinis minutiflora* and *Panicum maximum*.

Sampling of grasses was carried out throughout the period May 1957 to March 1958 and the samples were analysed for crude proteins, crude fat, crude fibre, total ash and silica. The grasses were cut down at the end of the dry season (end of March) and the samples of grasses collected on any of these dates represent the growth from the beginning of the growing season until the date of cutting. The grasses were sampled in the first two weeks of May, August, December and March, and represent the growths of 6 weeks, 4½ months, 8½ months and 11½ months respectively.

The stations on which sampling was carried out were Entebbe, Kawanda and Serere. Entebbe lies within the Lake Victoria ecological zone and Kawanda in a forest–elephant grass zone while Serere is in the scattered trees–short grass zone.

Table 1. Relative quantities of leaves and stems in grasses throughout year

Results expressed DM = 100

Grasses	*Locality*	*Ratio of leaves to stems*				*Percentage of leaves in whole plant*				*Average*
		May 1957	*Aug 1957*	*Dec 1957*	*Mar 1958*	*May 1957*	*Aug 1957*	*Dec 1957*	*Mar 1958*	
Brachiaria brizantha	*Entebbe*	0·58	0·46	0·73	0·63	37	32	42	39	38
	Kawanda	0·79	0·61	0·41	0·63	44	38	29	39	38
	Serere	0·79	0·59	0·54	1·46	44	37	35	59	44
Cenchrus ciliaris	*Entebbe*	0·87	0·38	0·97	1·00	47	28	49	50	44
	Kawanda	0·67	0·31	0·23	0·31	40	24	19	24	27
	Serere	0·70	0·65	0·70	1·04	41	39	41	51	43
Chloris gayana	*Entebbe*	0·48	0·73	0·89	0·42	32	42	47	30	38
	Kawanda	0·55	0·49	0·37	0·52	35	33	27	34	32
	Serere	0·46	0·51	0·71	1·46	32	34	41	59	42
Hyparrhenia rufa	*Entebbe*	0·34	0·22	0·49	—	25	18	33	—	25
	Kawanda	0·50	0·17	0·23	0·30	33	15	19	23	23
	Serere	0·61	0·37	0·30	0·32	38	27	23	24	28
Melinis minutiflora	*Entebbe*	0·86	0·70	0·72	0·96	46	41	42	49	45
	Kawanda	0·63	0·54	—	—	39	35	—	—	37
	Serere	0·72	1·15	1·48	1·26	42	53	59	56	53
Panicum maximum	*Entebbe*	0·43	0·48	0·67	0·36	30	33	40	26	32
	Kawanda	0·99	0·40	0·49	0·62	50	29	33	58	38
	Serere	1·17	1·42	1·11	1·08	54	59	53	52	55

Analysis of variance: between species, $P < 0{\cdot}001$; between stations, $P < 0{\cdot}001$; between stages of growth, $P < 0{\cdot}05$.

The soil at Entebbe is sandy loam which is low in minerals and organic matter with the exception of phosphorus. The soil at Kawanda is a loam of high fertility. Serere soil is sandy loam, low in minerals and bases and deficient in organic matter. The distribution of rainfall is not identical for all stations and the rainfall of the three stations is therefore given in Appendix I.

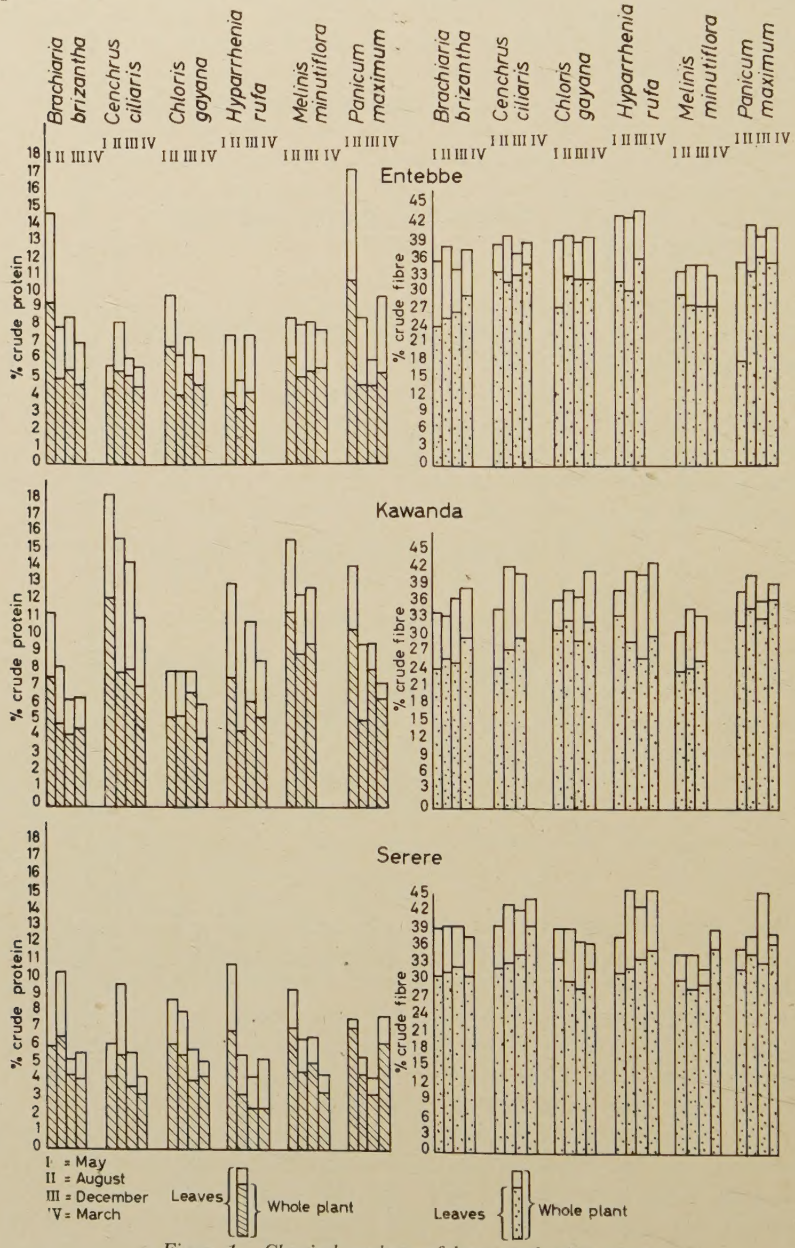

Figure 1. Chemical analyses of leaves and whole plants

The digestible crude proteins were calculated from the results of chemical analysis using the equation proposed by GLOVER and FRENCH (1957). Other digestible nutrients were calculated according to WALKER and HEPBURN (1955) and then were used for calculation of starch equivalent adopting KELLNER's (1926) method.

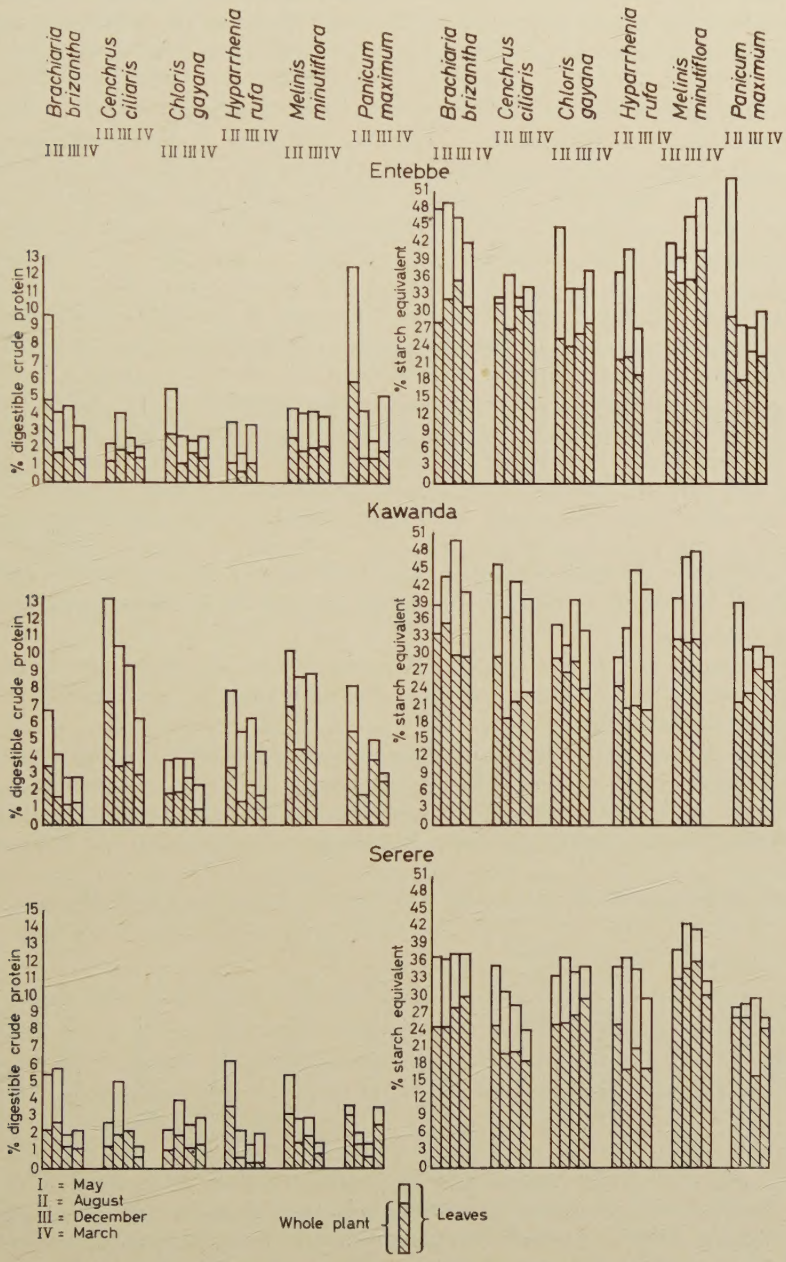

Figure 2. Calculated values of digestible proteins and starch equivalent

RESULTS

The first samples of grasses collected in May represented approximately six weeks growth and at this stage the stems were fairly well developed. The August collection can be described as a late flowering stage, although the term cannot be interpreted in the same way as in a temperate climate. The flowering habits of grasses within and between the species are very irregular and consequently flowering occurs during a prolonged period of time. The collection in December represented the stage in which the growth of grasses was considerably slowed down producing a small quantity of leaves, but very little stems. The last collection in March represented the stage of growth of grasses during the end of the dry season, at which stage most parts of the plants had died. *Table 1* shows the ratio of leaves to stems and the percentage of leaves in the whole plant, based on dry weights, throughout the year as clipped for analysis. The results of analysis of variance of the percentage of leaves in the whole plant which are given at the end of *Table 1* show that after six weeks of growth the variation in the percentage of leaves in the whole plant is influenced more by species of grasses, and various climatic conditions, than by the stage of growth of grasses. The initial period of up to six weeks of growth was not investigated, but it is clear that from the time the grasses were cut to the time of formation of the stems the percentage of leaves in the whole plant would vary from 100 per cent initially to the quantity shown at the time of first cutting. At the same time the results in *Table 1* indicate that the percentage of leaves in the whole plant and the ratio of leaves to stems in August are lower than in the May collection, but there is some increase in December, while in the March collection the results are still higher than those for the May collection.

The results of chemical analysis of leaves and whole plants are shown in *Figure 1* while the calculated values of digestible proteins and starch equivalent are given in *Figure 2*.

There is a considerable difference in the chemical composition between leaves and whole plants and the summary of results representing the nutrients in leaves expressed as percentages of corresponding nutrients in whole plants is given in *Table 2*. It can be seen from this table that

Table 2. Nutrients of leaves expressed as percentages of nutrients of whole plant

Nutrients	*Entebbe*			*Kawanda*			*Serere*		
	Min.	*Max.*	*Average*	*Min.*	*Max.*	*Average*	*Min.*	*Max.*	*Average*
Crude protein	123	182	*152*	112	188	*151*	107	220	*145*
Crude fat	107	172	*138*	113	207	*150*	115	195	*140*
Crude fibre	53	90	*79*	64	94	*77*	70	97	*83*
Silica-free ash	73	203	*123*	62	168	*106*	73	220	*115*
Nitrogen-free extract	96	118	*106*	94	122	*107*	95	111	*105*
Digestible crude protein	135	295	*211*	132	418	*215*	116	615	*223*
Starch equivalent	104	181	*139*	113	215	*150*	108	234	*135*

the content of crude protein and fat is always higher in leaves than in the whole plant, while crude fibre content is lower, silica-free ash and nitrogen-free extract content varies but is usually higher in leaves than in the whole plant.

DISCUSSION

Ratio of leaves to whole plant

The results of *Table 1* indicate that after the initial six weeks of growth, there is little change in the ratio of leaves to the whole plant, although there is a tendency for the ratio to decrease up to four months of growth and then to increase to that of six weeks of growth. The lowest ratios appear to coincide with the time of the full development of seeds, and after that time, the ratio increases.

Crude protein

The protein content of leaves and stems shows a pronounced pattern in all grasses with the exception of *Hyparrhenia rufa*. The percentages of protein in the leaves of these grasses, as related to those of whole plants, increase in the first few months of growth, followed by a decrease in the further stages of growth. At the same time the percentage content of crude protein in the leaves and in the whole plant decreases in the first few months of growth and then remains at approximately the same level throughout the rest of the year.

With *Hyparrhenia rufa* the highest proportion of crude proteins of leaves as related to that of the whole plant appears to be at the end of the dry season.

Crude fat

All results show that the fat content of the leaves is higher than that of the whole plant and the relation of the fat content of the leaves and the whole plants is of a similar pattern to that of the crude proteins.

Crude fibre

In all grasses at any stage of growth the percentage of crude fibre in leaves is lower than that of the whole plants and the main increase in the crude fibre content of leaves and whole plants, although it varies with species and station, appears to be in the early stages of growth. Thus after six weeks of growth there is already a considerable amount of crude fibre in both leaves and whole plants and there are only small increases of fibre in further stages of growth. This suggests that the main increase in crude fibre content is in the first six weeks of growth of the plant.

Digestible crude protein and starch equivalent

The contents of digestible crude proteins and of starch equivalents were consistently higher in the leaves than in the whole plants. Digestible crude proteins decrease with age of grasses but the main decrease occurs in the first four months of growth.

There is less variation throughout the year in starch equivalent than in the digestible crude proteins, but it varies with species and station.

Assuming that two per cent of digestible crude proteins and 24 per cent starch equivalent of the dry matter of grass, eaten by cattle, are the least quantities required for maintenance, it can be seen from *Figure 2* that there

is only a short period during the growth of grasses when cattle would satisfy their maintenance requirements if they grazed the whole plants without selection.

At the same time the nutritive values of leaves show that the level of starch equivalent is above maintenance throughout the year, and there is a sufficient quantity of digestible crude proteins for maintenance with the exception of *Hyparrhenia rufa* collected from Serere in December and *Melinis minutiflora* collected from Serere in December and March.

This does not mean that the animals actually obtain these values by selection, but indicates what nutrients are available for selection. If the findings of HARDISON *et al.* (1954) are accepted for Uganda conditions, the actual values of grass consumed by cattle would lie somewhere between the values of the leaves and of the whole plants. The best example of how much the protein value of the whole plant can vary from that of the leaves and to what extent it is possible for the animal to improve the intake of proteins by selective grazing, is provided by *Hyparrhenia rufa* collected from Serere in March, where the digestible crude proteins of the whole plant were only 0·32 per cent and of the leaves 1·97 per cent respectively.

This might explain how the local cattle can survive all the year round in areas where *Hyparrhenia rufa* is one of the predominant grasses although the chemical composition of the whole plant when taken as an indication of the consumed grass contains sufficient nutrients to meet the requirement of the cattle only when grass is very young. This also emphasizes the importance of the growth of leaves which can be encouraged by close grazing in the under-populated areas even if that could mean some small reduction in the total grass production.

SUMMARY

The chemical composition of leaves of *Brachiaria brizantha*, *Cenchrus ciliaris*, *Chloris gayana*, *Hyparrhenia rufa*, *Melinis minutiflora* and *Panicum maximum*, in relation to that of the whole plant was studied throughout a period of twelve months under three different climatic conditions in Uganda.

It was found that the changes in the ratio of the leaves to the whole plant were influenced more by the climatic conditions and by the species of grasses than by the length of growth after an initial period of six weeks. The percentage of crude proteins, crude fats, starch equivalent and digestible proteins are considerably higher in leaves than in the whole plant, while the crude fibre is lower. These higher nutritive values of leaves allow the cattle to make a better use of the pasture than indicated by the analysis of the clippings of the whole plant which is the normal routine of sampling for the estimation of the nutritive value of the pasture.

It was found that the extent to which the percentage of proteins in leaf is higher than that of whole plant varies considerably between grasses.

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Entebbe for permission to collect samples from their grass plots. Acknowledgement is due to the Chief Research Officer, Animal Health Research Centre for his comments and advice, and to the Director of Veterinary Services and Animal Industry for permission to publish this paper.

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Appendix I. Monthly rainfall, in., 1957/58

Station	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Entebbe	7·27	11·50	7·00	4·53	2·75	1·74	0·43
Kawanda	5·82	10·27	9·42	3·07	3·11	0·95	3·06
Serere	4·13	10·38	7·25	5·98	3·17	6·10	1·54
Station	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Total*
Entebbe	3·52	8·01	4·86	4·11	3·04	4·63	63·39
Kawanda	4·99	2·47	3·06	1·55	2·63	3·00	53·40
Serere	3·61	3·33	2·13	1·86	2·84	3·61	55·93

Studies on Pangola Grass at I.C.T.A., Trinidad—II

The Digestibility of Pangola Grass at Various Stages of Growth

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Pangola grass (*Digitaria decumbens*, Stent.) has been widely used in the Caribbean and Latin America for several years, but little has been published regarding its nutritive value. Bressani *et al.* (1958) determined the digestibility coefficients of samples of the grass cut at about the same stage of growth during the wet season; but these were somewhat similar in chemical composition. It is well known that in addition to the normal changes in chemical composition that occur as the plant matures, changes may be brought about by differing methods of management including fertilization, speed of rotation and stocking rate. It was of interest therefore to investigate the digestibility coefficients of various samples of Pangola grass with as widely differing chemical composition as possible, so that the effects of differing methods of management on the nutritive value of the pasture could be assessed.

EXPERIMENTAL PROCEDURE

Source of material

The Pangola grass for the four digestibility trials to be described was obtained from the farm of the Imperial College of Tropical Agriculture at Champs Fleurs, Trinidad.

The herbage used at the beginning of Trials 1, 2, 3 and 4 was 10 days, 15 days, 21 days and 42 days growth after grazing, respectively. The grass used in Trials 1 and 2 was therefore young, that used in Trial 3 was at a mature preflowering stage and that used in Trial 4 was mature and flowering. Herbage was cut daily and fed to the sheep on the same day. All trials were carried out in the wet season.

Digestibility trial procedure

The animals used were groups of 6 Persian Blackhead wethers with weights ranging from 70 to 100 lb. The trials consisted of a 7-day preliminary period and a 10-day collection period; during the whole trial the sheep were kept in individual cages with steel-grid floors covered with zinc mesh to separate faeces from urine. Animals were fed twice each day and faeces and urine were collected once. The herbage offered was sampled every morning for analysis. During the preliminary period, the quantity of herbage that

the animals would eat readily was determined so that during the collection period, refusals could be eliminated as far as possible whilst still feeding the wethers to appetite.

Analysis of samples

Duplicate determinations of dry matter by oven drying at 100° to 102°C for 24 hours were made on the herbage samples as soon as they were collected. The faeces samples were divided into two parts, one of which was used for determination of dry matter and the other was kept at 1°C prior to vacuum drying and subsequent estimation of nitrogen. (This was to avoid loss of nitrogen as ammonia caused by drying at high temperatures.) All samples were milled to pass a 1 mm sieve after drying, and bulked for proximate analysis.

Determinations of crude protein (Kjeldahl nitrogen × 6·25), crude fibre, ether extract and ash were made on the dried and milled herbage. Determinations of ash and crude protein were made on the vacuum-dried faeces, whilst the faeces that had been dried daily were analysed for ether extract and fibre. All determinations were made in duplicate. The methods used were those laid down by the Association of Official Agricultural Chemists (1955).

RESULTS AND DISCUSSION

The chemical composition and digestibility coefficients of the various samples of Pangola grass used in these trials are set out in *Tables 1* to *5*. The effect of increasing maturity of the grass can be clearly seen in *Table 1*.

Table 1. Percentage chemical composition of Pangola grass at different stages of growth

Constituent	*Trial 1*		*Trial 2*		*Trial 3*		*Trial 4*	
Age of herbage	*10 days*		*15 days*		*21 days*		*42 days*	
Condition	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*
Moisture	85·2	0	79·7	0	78·6	0	78·9	0
Crude protein	2·2	14·9	2·8	13·8	2·0	9·2	1·0	4·8
Crude fibre	4·6	31·0	6·0	29·6	7·5	35·3	7·6	36·3
Ether extract	0·4	2·9	0·7	3·5	0·5	2·3	0·2	1·0
Ash	1·7	11·4	2·2	10·9	2·6	12·2	1·5	6·9
Nitrogen-free extractives	5·9	39·8	8·6	42·2	8·8	41·0	10·8	51·0
Organic matter	13·1	88·6	18·1	89·1	18·8	87·8	19·6	93·1

With advancing age, the percentage of protein in the sample declines and the percentage of fibre increases. (The herbages used in Trials 1 and 2 were very similar in composition and the fibre level of that used in Trial 1 was in fact slightly higher than that used in Trial 2 when expressed on a dry

matter basis.) The effects of increasing age and consequent decrease in percentage of protein on nutritive value may be seen by reference to the tables.

Table 2. Digestibility coefficients of nutrients of 10 day old Pangola grass (as determined in Trial 1)

Constituent	Sheep No. 13	18	23	28	32	38	Mean
Crude protein	71·1	71·5	68·1	73·0	72·0	73·1	71·5
Crude fibre	73·4	71·3	70·0	71·7	69·9	71·0	71·2
Ether extract	55·9	50·0	49·9	51·0	49·8	49·0	50·9
Nitrogen-free extractives	63·2	60·8	60·1	61·8	62·9	63·2	62·0
Organic matter	67·8	65·9	64·6	66·8	66·4	67·1	66·4
Total digestible nutrients							60·7

Table 3. Digestibility coefficients of nutrients of 15 day old Pangola grass (as determined in Trial 2)

Constituent	Sheep No. 11	13	18	19	22	23	Mean
Crude protein	67·3	66·7	66·9	66·0	63·5	63·2	65·6
Crude fibre	68·9	71·3	71·6	69·0	67·5	68·7	69·5
Ether extract	45·6	42·9	47·3	37·7	35·6	32·1	40·2
Nitrogen-free extractives	62·5	62·3	65·3	59·1	57·9	59·1	61·0
Organic matter	64·7	65·2	66·9	62·6	61·1	61·9	63·7
Total digestible nutrients							58·5

Table 4. Digestibility coefficients of the nutrients of 21 day old Pangola grass (as determined in Trial 3)

Constituent	Sheep No. 13	18	19*	22	23	28	Mean
Crude protein	57·2	62·4	56·2	57·4	55·1	57·4	57·6
Crude fibre	66·5	71·0	65·0	63·4	63·8	67·0	66·1
Ether extract	12·0	21·7	6·9	15·8	38·7	33·5	12·1
Nitrogen-free extractives	60·8	61·0	53·2	63·5	57·1	57·7	59·0
Organic matter	61·4	64·1	57·0	61·9	59·1	60·8	60·7
Total digestible nutrients							53·5

* This sheep was made atypical by a dehorning operation at the beginning of the collection period.

Table 5. Digestibility coefficients of the nutrients of 42 day old Pangola grass (as determined in Trial 4)

Constituent	Sheep no. 13	18	19	22	23	28	Mean
Crude protein	14·5	13·1	17·0	28·4	12·5	27·1	18·8
Crude fibre	56·4	62·8	60·0	60·6	55·6	61·5	59·5
Ether extract	−20·8	− 8·4	−26·9	−11·8	−29·5	−17·9	−19·2
Nitrogen-free extractives	52·7	59·5	54·9	59·6	53·1	57·1	56·2
Organic matter	51·3	57·7	51·8	57·6	51·1	56·5	54·3
Total digestible nutrients							51·2

The digestibility of the protein in the grass decreased in like manner to the percentage of the protein in the grass. This has previously been noted by several workers including GLOVER *et al.* (1957) who related the percentage of protein in the grass to its digestibility coefficient by means of the expression

Digestibility coefficient = 70(log % protein in dry matter) − 15. The results obtained for the digestibility coefficients in Trials 1, 2 and 3 agree closely with the values predicted using the above equation, the difference in percentage being +4·5, +0·9 and +5·0 respectively. In Trial 4, however, the predicted value is considerably higher than that obtained by experiment (32·6 as opposed to 18·8). This is not altogether surprising in view of the known variability of samples containing a small amount of protein; Mitchell (1942) has in fact implied that the digestibility coefficient may be nil at the five per cent level. It also confirms the inadequacy of the general equation with herbage of low protein content.

It is interesting that the values obtained in Guatemala by Bressani *et al.* (1958) for digestibility coefficients of Pangola containing 9·8 and 9·2 per cent protein (87·3 and 64·1 respectively) are considerably higher than those indicated by the general equation of Glover *et al.* (1957), and by the present work. No explanation can be suggested for this discrepancy.

The digestibility of crude fibre and of nitrogen-free extractives is also lower in the samples with a lower percentage of protein. There is thus a decrease in total digestible nutrients but this is buffered to a certain extent by the increase in the quantities of these fractions present. It is interesting to note that in all cases, the digestibility coefficient of the crude fibre fraction is higher than that of the nitrogen-free extractives. This is probably because lignification of the cell walls partially prevents access of the rumen micro-organisms to the cell contents where the highest concentration of nitrogen-free extractives is to be found.

The ' negative coefficients ' of digestibility of approximately −20 per cent obtained for the ether extract fraction of the grass in Trial 4 are unusual. Bressani *et al.* (1958) suggested that a possible synthesis of ether-soluble material by micro-organisms in the alimentary canal could cause high variability in these values, but it is probable that the high experimental error associated with the determination of low quantities of ether-extractable material is also a contributory factor.

Duckworth (1958) has computed that the range of protein content of herbage should be within 8 to 12 per cent of dry matter for efficient beef production and it is likely that the same levels are valid for dairy production. It is clear that although Pangola grass is capable of these and higher levels of protein production under good systems of management, it may easily be allowed to deteriorate in quality to such an extent that production will be considerably impaired. This is especially so when Pangola grass is grown in areas of high seasonal variation in rainfall without irrigation, when grass surpluses will accumulate in the rainy season and will be grazed long past the stage at which optimal nutritional quality is achieved (Unsworth *et al.* 1959). From the point of view of nutritive value it is clear that it is best to graze Pangola grass at as early a stage of growth as possible, in order to exploit its potential to greatest advantage.

SUMMARY

Determinations of digestibility coefficients were carried out on four samples of Pangola grass at differing stages of growth and chemical composition. The technique used was measurement of feed intake and faecal

output of Blackhead Persian wethers housed in specially constructed digestibility cages. It was shown that as the content of protein in the grass decreased, so did its digestibility; in the first three trials this was in accordance with values predicted by using a general equation developed by other workers, but in the fourth trial, the value obtained experimentally was considerably lower than that predicted. This indicated the variability to be expected at low levels of protein. The digestibility coefficients both of the crude fibre fraction and of the nitrogen-free extractives also decreased as the percentage of protein went down, but this was partially compensated for by the increase in the amounts of these constituents. In the final trial, negative coefficients of digestibility were obtained for the ether extract fraction; the reason for these results is discussed. It was concluded that under good conditions of management Pangola grass was capable of high levels of protein production, but that deterioration could easily take place so that production would be seriously impaired.

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Yield and the Spacing of Tea

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Under natural conditions the tea plant (*Camellia sinensis*) grows into a flowering and fruit-bearing tree some thirty feet high. In cultivation, however, the plant is pruned at regular intervals to form a low bush suitable for the removal of young shoots from its surface. At a spacing of 4 ft × 4 ft square (2 720 plants/acre) the bushes are sufficiently close to form a nearly complete canopy over the soil surface; under average Nyasaland conditions lesser populations do not form a complete canopy.

The first tea to be planted in Nyasaland was spaced at 5 ft square (1 740 plants/acre); development in the 1930s turned to closer spacing at 4 ft square and in recent years the tendency has been to still closer spacing using various patterns yielding populations in the region of 3 500 plants/acre.

In the past there has been little experimental evidence to guide the industry on spacing and this paper presents collated data collected over ten years. Year by year the basic yield data have been published in the *Annual Reports* of the Station, after being subjected to formal statistical analysis, but no general rule was apparent until recently. In support of the Nyasaland results, data have been analysed from Assam and Indonesia.

Holliday (1960), reviewing literature and considering the results of his own experiments with European crops, points out that two main forms of yield/population curves exist. Those associated with yields from the reproductive parts of plants tend to be parabolic in shape indicating an optimum plant population above or below which yields decrease. Curves associated with the yield from vegetative parts of plants tend to be asymptotic indicating no absolute maximum yield or optimum spacing. With the asymptotic type of curve Holliday describes a linear relationship between the reciprocal of individual plant yield and plant population. The present paper offers evidence that linear relationships of this type hold good for tea and that interpolated yields from the transformed linear functions obey one general equation descriptive of yield against population for the three tea-growing countries from which data are available.

It must be noted that the yields presented below are taken from mixed seedling populations. Work in Assam and very recent work in Nyasaland may indicate that selected tea propagated as clones, in contrast to seedling populations, will require individual consideration for population rates. As yet no clonal selections have been tested for use by the Nyasaland industry and it is certain that for some years to come areas will continue to be planted with mixed seedlings. The investigation described below is therefore of immediate and future practical interest to the industry.

METHODS

Yield data from all sources were transformed into the reciprocal of yield/plant, $1/Y_p$. Linear regressions of the type

$$1/Y_p = a + b\,x$$

were calculated, where Y_p is the yield/plant, x the number of plants/acre at Y_p, b the regression coefficient of $1/Y_p$ on x, and a is the constant term. The accuracy of fit of the regression is described by the r^2 value, the coefficient of determination, and significance is determined thereon. Transformation of these linear functions leads to the theoretical asymptotic curves.

All estates have yield data from mature areas of tea spaced at 4 ft square; thus average data have been finally summarized as percentage comparisons with this standard.

In December 1951 an experiment was planted in the Mlanje district of Nyasaland comparing four plant populations and four nitrogen rates in factorial combination. There are three complete replications partially confounded between twelve blocks each of four plots. Each spacing treatment is thus replicated 12 times and plot size is $\frac{1}{12}$ acre. Spacing treatments compared are:

4 ft × 4 ft square	= 2 720 plants/acre
4 ft × 3 ft rectangular	= 3 630 plants/acre
5 ft × 2½ ft × 2½ ft double hedge	= 4 650 plants/acre
4 ft × 2 ft × 2 ft double hedge	= 7 260 plants/acre

There has been no interaction with nitrogen rates (*Annual Reports*, Nyasaland) and thus yields can be considered as simple main effects of spacing. This experiment is not shaded with permanent shade trees.

In 1952 there was an unfortunate accident leading to the uprooting and replanting of one complete replication. Yields according to age as presented below are therefore taken over two successive seasons for each age group.

The first complete replication of a sequence of three identical large complex experiments was planted in December 1952, again at Mlanje. The second and third replications followed at yearly intervals, thus giving a crude phasing over seasons (LAYCOCK, 1960). In these it is intended to compare at maturity four treatments each at three levels in factorial combination, but in the present juvenile stages only spacing and nitrogen treatments are in operation. Each experiment consists of 81 plots subdivided into 9 blocks each of 9 plots. Spacing treatments are thus replicated 27 times in each experiment and plot size is $\frac{1}{12}$ acre.

As with the first experiment, no interaction has occurred between spacing and nitrogen rates and therefore yields are again considered as arising from simple main treatment effects.

In each experiment the following spacing treatments are compared:

4 ft × 4 ft square	= 2 720 plants/acre
4 ft × 3 ft rectangular	= 3 630 plants/acre
4 ft × 2 ft × 2 ft double hedge	= 7 260 plants/ acre

Each experiment is shaded with *Grevillea robusta* trees planted originally at 24 ft square and thinned diagonally after five years to approximately 34 ft square.

In 1938 a randomized block experiment was planted in Mlanje and compared the effect on yield of four spacings each replicated four times. Plot size was 0·1 acre and nitrogen rates were equal over all plots. Spacings compared were:

5 ft × 5 ft square = 1 740 plants/acre
4½ ft × 4½ ft square = 2 150 plants/acre
4 ft × 4 ft square = 2 720 plants/acre
3½ ft × 3½ ft square = 3 560 plants/acre

In 1956 this experiment was superseded by the factorial experiments described above and yield data for a constant rate of 80 lb nitrogen (N) per acre are available for the five seasons 1951–52 to 1955–56 inclusive. (Prior to 1950 nitrogen rates were much lower; 80 lb nitrogen per acre is representative of the rate used generally throughout the industry.) This experiment is unshaded and pruned on a three year cycle.

Yield data are also available from two closely spaced non-experimental mature fields near to the experiment. The first field (16A) is 0·45 acre of 4 ft × 2 ft rectangular spacing (5 460 plants/acre) and the second (16B) is 1·23 acre of 4 ft × 3 ft rectangular spaced tea (3 630 plants/acre).

Tea in Nyasaland is transplanted to the field from the nursery as 30 month old stumps (Laycock, 1957). During the next 15 months it is left untouched and then receives its first field pruning. First yields are taken between 18 and 30 months after transplanting whereupon the tea receives its second field pruning. This annual sequence follows for the first eight seasons after which longer pruning cycles are introduced. Yields presented in the tables below are shown according to these age groups for the factorial experiments, whereas those from the oldest experiment are recorded as average mature yields (over 10 years from transplanting). The mature tea was pruned on a three year cycle.

The cropping season is recorded from July one year to June the next, which is from mid dry season through the rains to mid dry season. Pruning takes place in May–June and crop follows the rain pattern.

During the dry season of 1957 an unprecedented drought caused many deaths amongst young tea and seriously affected the original populations in the four factorial experiments. No deaths occurred in the mature fields. As a result it is necessary to divide yield tables for the four factorial experiments into pre- and post-drought results. The drought in effect increased the range of populations examined.

Assam data are taken from the 1955 *Annual Report* of the Tocklai Experimental Station, pages 63 to 66. Two year old seedlings were planted in the field in April 1949 at the following spacings, each plot being 0·02 acre and replicated three times:

4 ft × 4 ft square = 2 720 calculated plants/acre
5 ft × 2½ ft rectangular = 3 440 calculated plants/acre
5 ft × 2½ ft × 2½ ft double hedge = 4 590 calculated plants/acre
4 ft × 2 ft rectangular = 5 460 calculated plants/acre

Yield data are available from 1950 to 1955.

Data for the Indonesian experiment are quoted by VISSER and DE WAAS TILLEKERATNE (1958). Seed was planted at stake in January 1927 and first yields taken in 1930. The experiment was discontinued in 1942. The following planting distances were compared and average yields are available over 12½ years:

4 ft × 1 ft × 3 ft double hedge	= 6 695 counted plants/acre
4 ft × 4 ft rectangular	= 3 644 counted plants/acre
3 ft × 5 ft rectangular	= 2 953 counted plants/acre
4 ft × 5 ft rectangular	= 2 270 counted plants/acre
5 ft × 5 ft square	= 1 820 counted plants/acre
6 ft × 6 ft square	= 1 262 counted plants/acre

The first and last treatments were replicated twice and the remainder five times, plot size being 1 hectare (2·47 acres).

RESULTS

Table 1. Yield/acre of made (Nyasaland) tea against plant population from four spacing treatments in one experiment

(a) *Before 1957 drought*

Seasons	Age in months	Spacing arrangement and plants/acre							
		4 ft × 4 ft 2 720		4 ft × 3 ft 3 630		5 ft × 2½ ft × 2½ ft 4 650		4 ft × 2 ft × 2 ft 7 260	
		Yield	$1/Y_p$	*Yield*	$1/Y_p$	*Yield*	$1/Y_p$	*Yield*	$1/Y_p$
1953–55	18–30	134	20·30	155	23·42	159	29·22	171	42·46
1954–56	30–42	357	7·62	425	8·54	447	10·39	508	14·29
1955–57	42–54	977	2·78	1 101	3·30	1 142	4·07	1 302	5·58
1956–58	54–66	1 091	2·49	1 248	2·91	1 244	3·73	1 331	5·45

(b) *After 1957 drought*

Seasons	Age in months	Reduced plants/acre							
		2 280		2 970		3 720		5 680	
		Yield	$1/Y_p$	*Yield*	$1/Y_p$	*Yield*	$1/Y_p$	*Yield*	$1/Y_p$
1957–59	66–78	1 553	1·47	1 561	1·90	1 607	2·31	1 741	3·26
1958–60	78–90	1 325	1·72	1 357	2·19	1 405	2·65	1 491	3·81

Table 2. Yields/acre of made (Nyasaland) tea against plant population for the first replication of the 3-spacing experiment planted December 1952

(a) *Before 1957 drought*

Season	Age in months	Spacing arrangement and plants/acre					
		4 ft × 4 ft 2 720		4 ft × 3 ft 3 630		4 ft × 2 ft × 2 ft 7 260	
		Yield	$1/Y_p$	*Yield*	$1/Y_p$	*Yield*	$1/Y_p$
1954–55	18–30	108	25·19	124	29·27	158	45·94
1955–56	30–42	541	5·02	655	5·54	806	9·01
1956–57	42–54	1 116	2·44	1 288	2·82	1 646	4·41

(b) *After 1957 drought*

Season	Age in months	Reduced plants/acre					
		1 930		2 480		4 520	
		Yield	$1/Y_p$	Yield	$1/Y_p$	Yield	$1/Y_p$
1957–58	54–66	240	8·04	269	9·22	279	16·20
1958–59	66–78	786	2·46	854	2·90	968	4·67
1959–60	78–90	783	2·46	825	3·00	968	4·67

Table 3. Yields/acre of made (Nyasaland) tea against plant population for the second replication of the 3-spacing experiment planted in December 1953

(a) *Before 1957 drought*

Season	Age in months	Spacing arrangement and plants/acre					
		4 ft × 4 ft 2 720		4 ft × 3 ft 3 630		4 ft × 2 ft × 2 ft 7 260	
		Yield	$1/Y_p$	Yield	$1/Y_p$	Yield	$1/Y_p$
1955–56	18–30	369	7·37	439	8·27	538	13·49
1956–57	30–42	668	4·07	764	4·75	949	7·65

(b) *After 1957 drought*

Season	Age in months	Reduced plants/acre					
		2 210		2 870		5 110	
		Yield	$1/Y_p$	Yield	$1/Y_p$	Yield	$1/Y_p$
1957–58	42–54	300	7·37	320	8·97	336	15·21
1958–59	54–66	936	2·37	1 020	2·81	1 099	4·65
1959–60	66–78	1 054	2·10	1 179	2·43	1 283	3·98

Table 4. Yields/acre of made (Nyasaland) tea against plant population for the third replication of the 3-spacing experiment planted in December 1954

(a) *Before 1957 drought*

Season	Age in months	Spacing arrangement and plants/acre					
		4 ft × 4 ft 2 720		4 ft × 3 ft 3 630		4 ft × 2 ft × 2 ft 7 260	
		Yield	$1/Y_p$	Yield	$1/Y_p$	Yield	$1/Y_p$
1956–57	18–30	228	11·93	266	13·68	365	19·89

(b) *After 1957 drought*

Season	Age in months	Reduced plants/acre					
		2 300		2 880		4 430	
		Yield	$1/Y_p$	Yield	$1/Y_p$	Yield	$1/Y_p$
1957–58	30–42	188	12·23	193	14·92	190	23·32
1958–59	42–54	571	4·03	601	4·79	683	6·49
1959–60	54–66	823	2·79	879	3·28	980	4·52

Table 5. Average annual yields/acre of made tea against plant population for mature Nyasaland tea for the seasons 1951–52 to 1955–56 inclusive

Area	Spacing	Plants/acre	Average annual yield, lb	$1/Y_p$
Experiment	5 ft × 5 ft	1 740	1 141	1·52
Experiment	4½ ft × 4½ ft	2 150	1 290	1·67
Experiment	4 ft × 4 ft	2 720	1 307	2·08
Experiment	3½ ft × 3½ ft	3 560	1 328	2·68
Field 16B	4 ft × 3 ft	3 630	1 394	2·60
Field 16A	4 ft × 2 ft	5 460	1 519	3·58

Table 6. Average annual yield/acre from Assam for the years 1950–55 inclusive according to spacing

Spacing	*Plants/acre*	*Average annual yield, lb*	$1/Y_p$
4 ft × 4 ft	2 720	656	4·15
5 ft × 2½ ft	3 440	667	5·16
5 ft – 2½ ft × 2½ ft	4 590	703	6·53
4 ft × 2 ft	5 460	745	7·33

Table 7. Average annual yield/acre from Indonesia for the 12½ years 1930–42 inclusive according to spacing

Spacing	*Plants/acre*	*Average annual yield, lb*	$1/Y_p$
6 ft × 6 ft	1 262	850	1·48
5 ft × 5 ft	1 820	1 051	1·73
4 ft × 5 ft	2 270	1 083	2·10
3 ft × 5 ft	2 953	1 171	2·52
4 ft × 3 ft	3 644	1 130	3·22
4 ft × 1 ft × 3 ft	6 695	1 234	5·43

Detailed yields according to age, $1/Y_p$ values, regression functions and averages are presented in *Tables 1* to *8*. The data in *Tables 1* to *7* were analysed leading to the linear functions of $1/Y_p$ on x given in *Table 8* together with the average function for each age group.

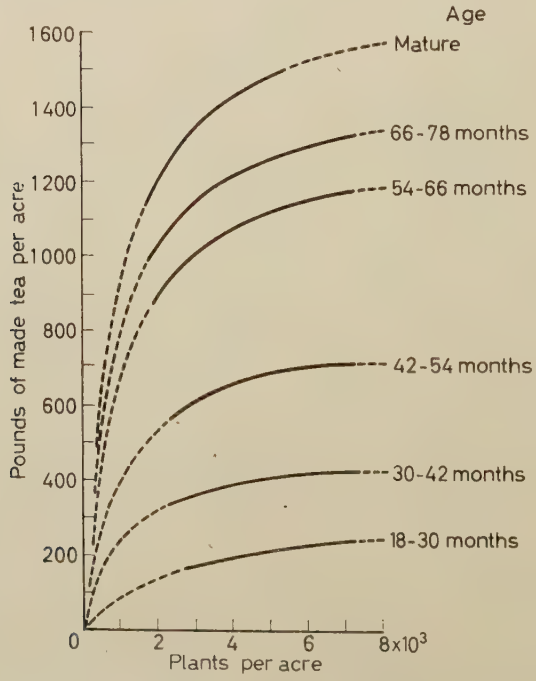

Figure 1. Increase in yield per acre according to plant population and age, Nyasaland data.——Interpolated. - - - -Extrapolated

Table 8. Linear regression equations of $1/Y_p$ on x for various ages of tea and for average values

Age in months	*Seasons*	*Reference to accompanying Table*	*Regression function of $1/Y_p$ on plant population (x)*	*r^2 value*	*Significance*
18–30	1953–55	1 a	$1/Y_p=0{\cdot}004,\ 984,\ x+\ 6{\cdot}10$	0·9964	$P=0{\cdot}001$
	1954–55	2 a	$1/Y_p=0{\cdot}004,\ 577,\ x+12{\cdot}71$	0·9999	$P=0{\cdot}001$
	1955–56	3 a	$1/Y_p=0{\cdot}001,\ 373,\ x+\ 3{\cdot}48$	0·9971	$P=0{\cdot}05$
	1956–57	4 a	$1/Y_p=0{\cdot}001,\ 743,\ x+\ 7{\cdot}25$	0·9997	$P=0{\cdot}01$
18–30	*Average*	—	$1/Y_p=0{\cdot}003,\ 169,\ x+\ 7{\cdot}39$	—	—
30–42	1954–56	1 a	$1/Y_p=0{\cdot}001,\ 502,\ x+\ 3{\cdot}35$	0·9981	$P=0{\cdot}001$
	1955–56	2 a	$1/Y_p=0{\cdot}000,\ 901,\ x+\ 2{\cdot}43$	0·9950	$P=0{\cdot}05$
	1956–57	3 a	$1/Y_p=0{\cdot}000,\ 791,\ x+\ 1{\cdot}90$	0·9999	$P=0{\cdot}01$
	1957–58	4 b	$1/Y_p=0{\cdot}005,\ 250,\ x+\ 0{\cdot}02$	0·9990	$P=0{\cdot}01$
30–42	*Average*	—	$1/Y_p=0{\cdot}002,\ 111,\ x+\ 1{\cdot}92$	—	—
42–54	1955–57	1 a	$1/Y_p=0{\cdot}000,\ 621,\ x+\ 1{\cdot}10$	0·9975	$P=0{\cdot}001$
	1956–57	2 a	$1/Y_p=0{\cdot}000,\ 435,\ x+\ 1{\cdot}25$	0·9999	$P=0{\cdot}01$
	1957–58	3 b	$1/Y_p=0{\cdot}002,\ 724,\ x+\ 1{\cdot}27$	0·9994	$P=0{\cdot}01$
	1958–59	4 b	$1/Y_p=0{\cdot}001,\ 143,\ x+\ 1{\cdot}44$	0·9984	$P=0{\cdot}05$
42–54	*Average*	—	$1/Y_p=0{\cdot}001,\ 231,\ x+\ 1{\cdot}27$	—	—
54–66	1956–58	1 a	$1/Y_p=0{\cdot}000,\ 666,\ x+\ 0{\cdot}61$	0·9962	$P=0{\cdot}001$
	1957–58	2 b	$1/Y_p=0{\cdot}003,\ 224,\ x+\ 1{\cdot}55$	0·9953	$P=0{\cdot}05$
	1958–59	3 b	$1/Y_p=0{\cdot}000,\ 798,\ x+\ 0{\cdot}56$	0·9989	$P=0{\cdot}01$
	1959–60	4 b	$1/Y_p=0{\cdot}000,\ 809,\ x+\ 0{\cdot}94$	0·9999	$P=0{\cdot}001$
54–66	*Average*	—	$1/Y_p=0{\cdot}001,\ 374,\ x+\ 0{\cdot}91$	—	—
66–78	1957–59	1 b	$1/Y_p=0{\cdot}000,\ 520,\ x+\ 0{\cdot}33$	0·9968	$P=0{\cdot}01$
	1958–59	2 b	$1/Y_p=0{\cdot}000,\ 857,\ x+\ 0{\cdot}79$	0·9998	$P=0{\cdot}01$
	1959–60	3 b	$1/Y_p=0{\cdot}000,\ 659,\ x+\ 0{\cdot}60$	0·9971	$P=0{\cdot}05$
66–78	*Average*	—	$1/Y_p=0{\cdot}000,\ 679,\ x+\ 0{\cdot}57$	—	—
78–90	1958–60	1 b	$1/Y_p=0{\cdot}000,\ 610,\ x+\ 0{\cdot}35$	0·9991	$P=0{\cdot}001$
	1959–60	2 b	$1/Y_p=0{\cdot}000,\ 857,\ x+\ 0{\cdot}79$	0·9998	$P=0{\cdot}01$
78–90	*Average*	—	$1/Y_p=0{\cdot}000,\ 733,\ x+\ 0{\cdot}57$	—	—
Mature Nyasaland	1951–56	5	$1/Y_p=0{\cdot}000,\ 572,\ x+\ 0{\cdot}52$	0·9915	$P=0{\cdot}001$
Assam	1951–55	6	$1/Y_p=0{\cdot}001,\ 162,\ x+\ 1{\cdot}09$	0·9938	$P=0{\cdot}01$
Indonesia	1930–42	7	$1/Y_p=0{\cdot}000,\ 744,\ x+\ 0{\cdot}51$	0·9968	$P=0{\cdot}001$

Average yields, calculated from the transformed functions, for young and mature tea in Nyasaland are plotted in *Figure 1*. Only two readings are available for tea aged 78 to 90 months, and consequently this average has not been plotted.

Each regression shown in *Table 8* is statistically significant and indicates a good fit to the asymptotic type of curve.

A more easily applicable summary of the data is available in *Table 9* wherein yields calculated from the average curves of *Table 8* are expressed as percentages of the conventional 4 ft × 4 ft spacing (2 720 plants/acre).

Table 9. Average yields for various ages and plant populations expressed as percentages of 4 ft × 4 ft spacing (2 720 plants/acre)

Plants per acre	Nyasaland							Assam	Indonesia
	Age in months after planting								
	18–30	30–42	42–54	54–66	66–78	78–90	Mature		
1 000	65·9	69·9	68·2	69·6	71·2	72·4	69·9	69·4	72·1
2 000	85·9	91·8	91·2	91·7	92·2	92·5	91·7	91·6	92·6
2 720	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0
3 000	104·1	102·3	102·7	102·4	102·3	102·2	102·4	102·2	102·1
4 000	117·0	108·7	109·5	108·8	108·2	107·6	108·7	108·9	107·8
5 000	126·4	113·0	114·2	113·1	112·1	111·3	112·8	113·1	111·5
6 000	133·5	115·8	117·4	116·1	114·8	113·9	115·9	116·3	114·0
7 000	139·4	118·3	120·0	118·4	116·9	115·8	118·1	118·4	116·0
8 000	143·5	119·7	121·8	120·1	118·5	117·3	119·7	120·3	117·4

For Nyasaland there is a close similarity between percentages after 18 to 30 months, at which age it is possible that competition between plants is not yet complete. The Assam and Indonesian percentages are again similar to the Nyasaland ones, and this leads to the suggestion that one average function can be satisfactorily descriptive for these three countries. This is $1/Y_p = 0{\cdot}001\ 242\,x + 1{\cdot}07$, and percentages calculated therefrom in relationship to 4 ft × 4 ft spaced tea are given in *Table 10*.

Table 10. Percentage comparisons of yield between 2 720 bushes/acre and other populations calculated from the averages of Nyasaland, Assam and Indonesian functions

Plants/acre	1 000	2 000	2 720	3 000	4 000	5 000	6 000	7 000	8 000
% yield	70·9	92·1	100·0	102·3	108·3	112·4	115·2	117·3	119·0

DISCUSSION

The results suggest that asymptotic curves calculated from the reciprocal of individual plant yields give adequate fits to actual yield data. The proportionate increases in crop with increase in population are remarkably consistent between ages and between countries. As a result one equation has been calculated which gives proportionate yields for the three countries. These curves should be of practical value.

The basic data from all countries are taken from a number of spacing patterns; thus square, rectangular, single and double hedge planted tea are represented. Proportionate yields do not appear to be affected by pattern, provided there is an even and systematic spread of bushes over the entire area. Three major practical considerations enter the choice of

pattern. First, all field management methods in Nyasaland are at present done by hand and the arrangement must enable the average man to reach all parts of all bushes. This in effect means that bushes should be planted so that the farthest point of reach is not more than 2 ft 6 in. away. Secondly, estates are becoming more conscious of conservation measures and, thirdly, thought is consistently being given to mechanization with, however, little practical field success as yet in Nyasaland. These three considerations have led in recent years to a turning away from straight row planting to contour systems using five foot between-row spacing. A basic planting pattern of this nature, whilst satisfying the first two considerations, and possibly the third, at the same time lends itself admirably to increasing the numbers of bushes per acre without further practical complications.

Three of the Nyasaland experiments are shaded with *Grevillea robusta* trees and two are unshaded. This shade tree has not affected the proportionate yield increases. No information on shade is available from the Assam and Indonesian experiments. Under Nyasaland conditions therefore it appears that this type of shade can be considered independently of spacing, other than for the purely practical purposes of field management.

Up to the ninth year after planting no interaction between plant population and nitrogen applications has appeared. It is considered therefore that nitrogen applications can be regarded independently of spacing in default of further information.

Fears are often expressed that the lower rainfall areas of Nyasaland could not support high plant populations. Undoubtedly the numbers of deaths per acre in young tea caused by the 1957 drought were in positive and significant proportion to the original numbers of plants/acre (*Annual Report*, Nyasaland 1957–58), but this drought was quite exceptional. Data analysed after the drought and as yet unpublished pending the results of a field trial, indicate strongly that a later pruning time than is used at present for immature tea can offer considerable protection against drought hazard. (After the first eight years unpruned tea is in little danger and a return to the normal and earlier pruning time for maximum yield production is indicated.) Nyasaland data for immature and mature yields are replicated over four or five seasons, including the drought of 1957 and the recovery period thereafter into 1958. The individual curves show that except in the abnormal drought period, the proportionate yield differences according to population vary only little from season to season. In view of this it appears that although average yields will be lower in the drier areas, increases in the proportion shown in *Table 10* can nevertheless be expected and that fears of excessive plant populations are unfounded.

Because the curves are asymptotic it follows that no physical optimum population can be determined. A decision upon the desired population level must therefore depend upon practical implications as outlined above and upon economic considerations. Parochial economics are not of wide general interest but in brief it can be demonstrated under Nyasaland conditions that the extra estimated capital and recurrent costs caused by increasing plant populations can be expected to return good profits at present-day prices. As costs per acre will inevitably increase, it becomes

more and more essential to increase yield/acre, and closer spacing than even the common present 3 500 plants/acre appears justified and economically desirable.

Table 10 illustrates a point of particular interest to those estates which have old fields planted at 5 ft square spacing (1 740 plants/acre). A theoretically complete stand would offer a yield of only 80 per cent of that from 4 ft × 4 ft square (2 720 plants/acre) and frequently management methods were not sufficiently advanced in the early days to ensure a nearly complete stand. Yields are therefore lower still and the evidence summarized in *Table 10* would argue favourably for uprooting and replanting of these fields.

In extension of this argument it follows that full potential yield will only be realized with a complete stand. The establishment of tea in the fields has received attention and the industry is better advised towards this aim than in the early days (LAYCOCK, 1957). Closer spacing has the additional advantage that, as populations increase, equal numbers of deaths will have decreasingly little effect on yields.

SUMMARY

An examination of yield data taken from various plant populations in Nyasaland, Assam and Indonesia shows that good fits can be obtained to asymptotic curves.

The proportionate increase in yield as population increases is remarkably consistent between age groups and countries. Consequently one curve was calculated which is of general applicability.

This curve yields no physical optimum plant population and the choice of population must depend upon practical and economic considerations. These are discussed and the arguments are in favour of higher populations than those used in the past or at present.

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Chemical Control of Transport and Storage Diseases of Bananas

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Problems associated with transportation and storage of large consignments of bananas have been reviewed by Wardlaw (1935). Extensive research carried out chiefly in Trinidad emphasized the importance of wastage due to fungal decay (Wardlaw, 1930, 1931 a, 1931 b; Wardlaw and McGuire, 1931 a, 1931 b, 1932, 1933). It was concluded that most fungal wastage is a direct consequence of mechanical damage caused to the fruit during cutting, handling or transport. Mechanical injuries include splitting, cracking, twisting and breaking across of the main-stalks*, wrenching-off of entire hands and, twisting, breaking-off, scratching and abrasion of individual fingers. Various pathogens readily invade the wounded tissues and may spread rapidly causing extensive rotting during ocean transportation and subsequent ripening.

There is little doubt that much fungal wastage could be prevented by handling fruit carefully at all stages between harvesting in the tropics and ripening at the final destination. Other recommendations include: (*1*) good organization to minimize the period of exposure of infected wounds to tropical temperatures, (*2*) rapid cooling of cargoes to approximately 53°F, (*3*) expeditious ripening, and (*4*) cleanliness in ripening rooms (Wardlaw, 1935).

In recent years, investigators in widely separated banana-growing regions have tested the possibility of controlling the major types of fruit-rot by chemical means. This field of research, although still in its infancy, has yielded some promising results and these are reviewed in the present paper.

EXTENT OF WASTAGE CAUSED BY FUNGI

There is little information in the literature concerning the amount of wastage caused by fruit-rot fungi. Tomkins (1931) considers it difficult to estimate the extent of wastage but suggests several methods which might be adopted. A general survey of the cargo is the method usually practised and the numbers of loose bananas which collect in the hold provides some indication of the condition of the shipment. Since the majority of loose bananas are rotted to some extent at the finger-stalk end, it is considered that the numbers observed will provide an index for finger-stalk rot. For Brazilian ' Cavendish ' bananas shipped to England there is marked seasonal variation in the value of this index (Tomkins, 1931). It is highest in December

* The terminology adopted here is that of Wardlaw (1935): ' The individual banana fruit may conveniently be described as "finger", and its short stalk as the "finger-stalk"; where several "finger-stalks" meet to form a "hand", a crescentic "cushion" is formed. These "cushions" project from the "main-stalk" of the whole bunch'.

and then decreases to a minimum in June. From June to December, there is a steady increase. Observations made at the port of discharge may not provide a very accurate estimate of wastage, for an apparently good cargo may, when observed later in the ripening room, be quite badly affected. Also, the quantity of wastage is markedly influenced by prevailing market demands. Thus, when fruit is plentiful and the price is low, bananas which at other times would be recovered are thrown away.

Similarly, there is little information about the extent of fungal wastage of Jamaican bananas imported into the United Kingdom. Reports describing the condition of newly arrived consignments have been studied and the numbers of unsaleable bunches were noted for each month during the three years 1957–59. There is a well defined seasonal trend in percentage ' unsaleables ', this trend being similar to that for loose bananas in Brazilian fruit. It is necessary to point out that bananas may be unsaleable for several different reasons, examples being under- or over-maturity, premature ripeness (' ship-ripes '), staleness (limp bunches), all forms of mechanical injury, fungal decay of fingers, finger-stalks and main-stalks, and all forms of blemish such as caterpillar scars, thrips injury, ' speckling ' (fruit-spot) and leaf-scar. Thus, the amount of wastage due to fungi is always less than the total wastage, which rarely exceeds 5 to 6 per cent of the shipment. After ripening it is often stated that a given percentage of fruit is affected, but this does not necessarily imply that it is all wasted. Some will be marketed as second or third class fruit of lower value.

Recently, the United Fruit Company (Anon., 1959) has attempted an analysis of wastage with the object of assessing the relative importance of finger-stalk rot. Fruit was shipped from Central and South America and examined after ripening in North America. A total of 209 196 lb of fruit was examined of which 6 486 lb (3·1 per cent) was affected by finger-stalk rot. However, only 1 019 lb (0·5 per cent) was discarded as waste. The total amount of waste was 27 303 lb or 13·0 per cent of the ripe weight inspected. Main-stalk rot accounted for most of this and finger-stalk rot for only 3·7 per cent. It is expected that the final analysis will indicate that finger-stalk rot accounts for about one sixth of the waste. It is also hoped to carry out similar analyses for fruit reaching European markets, and to investigate the relation between variety of banana and severity of disease.

ANTHRACNOSE

Nature and cause of disease

Banana anthracnose, also known as black-rot or ripe fruit-rot, is caused by *Gloeosporium musarum* Cke and Massee and has been recorded in most banana-growing regions. The disease has been recorded in the field on immature bananas (Agati, 1922) and plantains (Dastur, 1916; Park, 1930) but it is most commonly observed during transportation and storage of harvested fruit. Agati (1922) showed experimentally that *G. musarum* is able to infect very immature fruit still attached to the plant. Dastur (1916) had suggested previously that infection is normally initiated in the field, remaining in a dormant state until maturity—the ' latent infection ' hypothesis. Working in Trinidad, Baker and Wardlaw (1937) found that

surface-sterilized, immature bananas, when allowed to mature under aseptic conditions, developed anthracnose lesions. SIMMONDS and MITCHELL (1940) and SIMMONDS (1941) substantiated the latent infection hypothesis, for inoculation of immature fruit showed that infections remain superficial until a late stage of maturity. Fungal activity is then resumed, resulting in the development of typical lesions. CHAKRAVARTY (1957) has shown that penetration of the healthy, uninjured epidermis is effected by mechanical means. A slender infection hypha, developed from the appressorium, lies in a subcuticular position until maturity is approached; further tissue invasion then occurs. It was found that the expressed juice from green but not yellow banana peel inhibits germination and germ-tube elongation. This was suggested as the physiological basis of latency.

Anthracnose lesions developing from latent infections first appear on the yellow and almost fully mature banana as small, circular light-brown areas which may be slightly sunken. They rapidly increase in diameter at the ripening room temperature and, if many are present, often coalesce so that large areas of peel are affected (*Figure 1*). Bright salmon-coloured

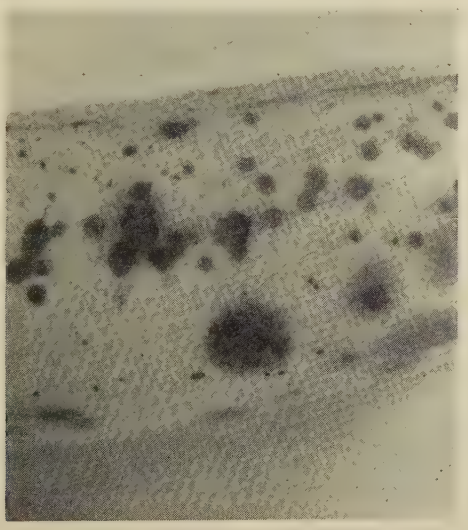

Figure 1. Anthracnose caused by G. musarum: *form of lesion characteristic of latent infection*

acervuli of *G. musarum* usually develop on the surface of the lesion. Although the lesions are quite superficial and do not extend deeply into the fruit pulp, the unattractive appearance of affected bananas considerably reduces their market value.

DELACROIX (1902) considered *G. musarum* to be a wound parasite and unable to infect uninjured bananas. The above-mentioned studies disprove this contention but, nevertheless, WARDLAW (1935) has emphasized the importance of mechanical injury as a factor favouring infection. MEREDITH (1960 b, c) investigated wound-parasitism by *G. musarum* with particular reference to Jamaican bananas. The fungus readily infects small scratches

on the skin of newly harvested, green ' Lacatan ' bananas. After 10 to 12 days storage at 55°F inside the holds of refrigerated cargo ships characteristic lesions develop. Each lesion is lenticular in outline, slightly sunken with a black centre and an orange yellow border (*Figure 2*). Lesions rapidly

Figure 2. Anthracnose caused by G. musarum: *form of lesion developing after wound-inoculation (non-latent infection)*

increase in size during the ripening process (carried out at 68° to 70°F). Histological studies indicate that, when acting as a wound parasite, *G. musarum* does not become dormant but rapidly invades the disorganized tissue. Because of this, it was suggested that the characteristic lenticular lesions should be referred to as ' non-latent anthracnose ' thus distinguishing it from the latent form of infection. Non-latent anthracnose is essentially a post-harvest disease and, unlike latent anthracnose, it can be observed on green fruit at the time of discharge from the ship. The severity of disease increases with increasing ' fullness ' of fruit at the time of harvest: also, the ' Lacatan ' and ' Robusta ' varieties are more susceptible than ' Gros Michel '.

Observations on fruit newly arrived in the United Kingdom from Jamaica, the Windward Islands, Canary Islands, British Cameroons and Fernando Po show that non-latent anthracnose often causes considerable wastage (Meredith, 1959). On the other hand, latent anthracnose is not of great economic importance provided that fruit is marketed before it is too ripe. If for some reason it cannot be distributed before full ripeness, some wastage may result from this type of infection.

Chemical control

Consideration of possible means of controlling anthracnose necessitates making a clear distinction between latent and non-latent infection. It is futile to attempt control of latent infection by spraying half-grown fruits with fungicides. At the time of spraying, the fungus may already be established in a subcuticular position. Even thorough surface-sterilization with corrosive sublimate and other chemicals does not impair later development of the fungus (SIMMONDS and MITCHELL, 1940). DASTUR (1916) notes that spraying plantain fruit with Burgundy mixture at fortnightly intervals, from the time when it was two months old until harvest, fails to control anthracnose. However, considerable reduction may be obtained when spraying is carried out at monthly intervals commencing immediately after the bunch has opened. SIMMONDS and MITCHELL (1940), working in Queensland, set up experiments to test Dastur's findings. Burgundy mixture was sprayed on to fruit at monthly intervals commencing: (*1*) immediately after fruit was uncovered by bracts, (*2*) one month after being uncovered, and (*3*) two months after being uncovered. There was some control using schedule 1, but none with schedules 2 or 3. The authors suggest that anthracnose was not completely prevented using the first schedule due to the intervals between successive sprayings being too long, or to the inefficiency of the fungicide. PARK (1930) states that Bordeaux mixture *or* lime sulphur sprays should provide equally good control, while DASTUR (1916) reports that a final spraying with ammoniacal carbonate, within a fortnight of reaping, will give adequate protection against infection and will not leave unsightly deposits on the fruit.

SIMMONDS and MITCHELL (1940) explored the effect of treating fruit after cutting. Fruit was dipped in various percentage concentrations of ' Shirlan ' AG (a 25 per cent suspension of salicylanilide in a ' wetting ' and ' spreading ' agent) immediately after cutting. Their results suggest that there was only slight to moderate reduction of anthracnose. Dipping in 4 to 8 per cent borax greatly reduced the amount of anthracnose, but it was considered that the difficulty of maintaining the solution at 50° to 54°C would unduly increase labour costs. Several other compounds have been tested, including the antifungal antibiotics actidione and nystatin, and the fungicides formalin, zineb, captan, thiram and nabam, but as might have been anticipated none of them gave any significant control of latent anthracnose (MEREDITH, unpublished).

Even if spraying in the field proves efficient in controlling anthracnose, it is doubtful if it would be practicable under Australian conditions. The hillside situation of the majority of plantations precludes the use of anything but the smallest type of spray unit. Also, the work and expense involved in covering even a small area would be excessive (SIMMONDS and MITCHELL, 1940). It is likely that similar practical difficulties would be encountered in other banana-growing countries, Jamaica being no exception. There is also the question of whether the amount of wastage caused by this form of disease justifies the expense involved in using chemical control measures. In the case of West Indian and West African fruit exported to the United Kingdom, there appears to be little justification for this.

The control of non-latent anthracnose is, at least for West Indian bananas, of considerably greater importance, for at certain times of the year almost every shipment is affected to some extent (Elders and Fyffes, Ltd, 1958). LEACH (1958) concluded that the largest proportion of mechanical injury to Jamaican bananas is caused between the time of harvest and that of loading on to the ship. The evidence suggests that the majority of naturally occurring, non-latent infections are initiated during this period. Two possible ways of controlling disease may be considered. First, fruit could be treated with fungicides just before or immediately after harvest. In this way many conidia of *G. musarum*, already present on the fruit surface (MEREDITH, 1960 d), would be killed. This may result in fewer abrasions and scratches becoming infected at a later stage. However, this possibility is complicated by the fact that, after harvest in Jamaica, fruit is wrapped in dead banana leaf ' trash '. This ' trash ' bears large numbers of acervuli of *G. musarum* and it is likely that re-contamination will occur. This might be prevented if, immediately after harvest, bunches were wrapped in plastic tubing so that there was no direct contact with ' trash '. But another consideration against fungicidal treatment in the field is the excessive expense involved in setting up hundreds of fungicidal tanks all over the island. Thus, it would be cheaper and more convenient to centralize fungicidal treatment at the five existing banana-loading wharves. A criticism here is that some fruit may not receive treatment for more than 24 hours after harvesting. Early established *Gloeosporium* infections may, therefore, be too advanced to control by most fungicides. Good organization would be necessary to minimize the interval between harvest and treatment.

The number of chemicals so far tested in an attempt to control non-latent anthracnose is small. However, the antifungal antibiotic nystatin* has been investigated in some detail. The *in vitro* activity of nystatin was studied by RANGASWAMI and DAMODARAN (1958), using the agar-streak dilution, the spore-germination and culture-disc assay methods. The inhibitory concentrations for *G. musarum* were 2·5, 12·5 and 50·0 p.p.m., respectively. Similar results were obtained in later experiments by BECCARI and GOLATO (1959). Preliminary tests on the use of nystatin under commercial conditions were carried out by CASTELLANI, BECCARI and MATTA (1958). Bananas were dipped in 0·04 per cent nystatin (in the form of ' Mycostatin 20 '—an agricultural grade of the antibiotic) suspension to which a ' wetter ' was added. They were then wrapped in polyethylene tubing, hermetically sealed and transported from Somalia to Italy on unrefrigerated ships. It is stated that the temperature at the fruit surface was, at certain periods, within the range 45° to 55°C. At the end of the 20-day voyage the fruit was examined for *Gloeosporium* infections. The data obtained suggested that there was some reduction of disease, although the nature of infection, that is, latent or non-latent, was not specified. The most remarkable finding from these tests was that treated fruit did not ripen or spoil while in transit, whereas control fruit was completely blackened and commercially useless. When the nystatin-treated fruit was unpacked and put in storage rooms, ripening was normal and the flavour was good.

* An account of this antibiotic is given by BROWN and HAZEN (1957).

A series of laboratory experiments demonstrated that nystatin can bring about appreciable reduction of wound infection by *G. musarum* (MEREDITH, 1960 b). Newly harvested ' Lacatan ' bananas were scratch-inoculated with *G. musarum* and, after various incubation periods at tropical temperatures, were dipped in various concentrations of nystatin plus a 'wetter'. Controls were dipped in water plus a ' wetter ' only. All fruit was wrapped in perforated polyethylene tubing and stored at 55°F for 12 days. It was then transferred to a ripening room (70°F) and the incidence of lenticular lesions was recorded at full maturity. The results from several experiments showed conclusively that nystatin is able to bring about reasonable control of wound-infection by *G. musarum*. A 9-hour incubation period prior to treatment did not impair the efficiency of the antibiotic, but in further experiments it was found that there was no significant control with incubation periods exceeding 30 hours.

Extensive commercial-scale trials with nystatin have been carried out on Jamaican bananas (MEREDITH, 1960 c). Fruit was dipped in nystatin (at 200 to 400 p.p.m.) just prior to loading on to the ship. Reports obtained from the United Kingdom indicated that this treatment effected 40 to 70 per cent reduction in anthracnose.

It is important to note that there may be some difficulty in using nystatin commercially. Being an antibiotic it may be subject to various regulations enforced by local food and drug authorities. However, it is stated that while on the surface of bananas, nystatin loses antibiotic activity within 5 to 10 days (Squibb and Sons Ltd, 1960). Also, preliminary biological assays provided no evidence that nystatin penetrates the fruit, for it was not detected either in peel or in pulp extracts (MEREDITH, unpublished). It is unlikely that the presence of nystatin merely on the skin of a banana could be deleterious to the health of the consumer.

The cost of treating Jamaican bananas with nystatin has been worked out assuming that the following conditions apply: that the antibiotic is used at a concentration of 400 p.p.m. and, for the five existing banana-loading wharves, a total of 40 dipping tanks are set up each week (each tank holds approximately 400 gallons): that every bunch of fruit for export is treated, totalling about 11 million bunches per annum. Making allowance for additional labour costs it is improbable that the average cost per bunch would exceed 2*d*. Expenses would be halved with 200 p.p.m. nystatin and the evidence suggests that this concentration is as effective as 400 p.p.m. (MEREDITH, 1960 c).

In screening candidate fungicides, the degree of phytotoxicity of each compound must be observed. The usual indication of phytotoxicity to bananas is a blackening of the peel. No phytotoxic effects have been observed on nystatin-treated fruit, but there was some delay in ripening (MEREDITH, 1960 b). Other compounds may also affect the ripening behaviour of the fruit and this must be studied in each case.

The widespread use of salicylanilide (' Shirlan ' AG) and its water-soluble sodium salt (' Shirlan ' WS) in Australia (see later) prompted some investigations carried out in Jamaica. In one shipping trial, fruit was dipped in 0·6 per cent ' Shirlan ' WS prior to loading (LEACH, 1956). Reports from the United Kingdom were unpromising, since all ' Shirlan '-

treated fruit displayed severe phytotoxic effects. There was, however, good control of anthracnose. In other experiments, carried out under laboratory conditions, it was found that phytotoxic effects were prevented if fruit was well rinsed in water after 1 to 2 minutes immersion in ' Shirlan ' WS (MEREDITH, 1960 d). With this schedule, there was approximately 80 per cent reduction in the incidence of lenticular anthracnose lesions. Percentage control decreased with increasing periods between inoculation and treatment, there being none after 24 hours. Several commercial-scale trials are being carried out to test this ' Shirlan ' WS–washing treatment. The results obtained so far are inconclusive due to the very low incidence of non-latent anthracnose in both treated and control fruit. However, no adverse reports concerning chemical injury have been received, thus confirming laboratory experience.

FINGER-STALK ROT

Nature and cause of disease

Finger-stalk rot, often referred to in the trade as ' Santa Marta stem-end rot ', develops when a finger is twisted, or forced inwards or outwards. The strain imposed on the relatively slender finger-stalk results in tissues being bruised if not ruptured. Infection of the wounded tissues by *G. musarum*, *Fusarium* spp. and other fungi is followed by rotting of the finger-stalk (*Figure 3*). At the time of discharge rot may be so advanced that it is

Figure 3. Finger-stalk rot caused by G. musarum *and* Fusarium *spp.*

difficult to handle fruit without causing ' finger-drop ': further dropping often occurs in the ripening room. TOMKINS (1931) considered ' finger-drop ' to be the most important source of wastage of Brazilian ' Cavendish ' bananas. This is sometimes true for Jamaican ' Lacatan ' and West African ' Gros Michel ' fruit (Elders and Fyffes Ltd, 1958).

Although several fungi may be associated with finger-stalk rot the evidence suggests that *G. musarum* is the most important. Other species isolated include *Ceratocystis paradoxa* (Dade) Moreau, *Botryodiplodia theobromae* Pat., *Verticillium* spp. and *Fusarium* spp.

Chemical control

One of the first detailed investigations on chemical control of finger-stalk rot was that of ANDRADE, PUZZI and TORRES (1956). Fruit grown on the coastal lowlands of São Paulo was harvested and then sprayed with, or dipped in, various concentrations of 'Shirlan' WS. It was shipped to London where assessments of disease severity were made. The data obtained suggest that spraying the complete bunch with a 0·6 per cent solution was better than other methods of application. It is claimed that the fungicide residue will protect wounds that occur during transportation.

Although large-scale shipment trials will provide the most useful information about the effectiveness of various fungicidal treatments, the expense involved may be prohibitive. When a large number of chemicals are to be tested, it is desirable to use smaller-scale laboratory screening techniques. In the first place, *in vitro* tests should be carried out on the organisms in question. This will be a routine procedure carried out in the knowledge that the results obtained may bear little relation to those *in vivo*. The next step is to devise a realistic inoculation technique, providing a relatively high fungal inoculum potential and favourable conditions for infection. PHELPS (1959) reports that a rapid method of inoculation of green fruit has been perfected. A spore suspension, or mycelium, of *G. musarum* is placed in knife cuts or needle pricks made in the finger-stalk. Typical symptoms of disease appear after 7 days storage at 65° to 80°F inside small incubators. When screening fungicides, fruit is surface-sterilized with 0·1 per cent chlorox, inoculated, incubated for 2 days and then dipped for 1 minute in the test compound. With this technique the fungicides 'Shirlan' WS, maneb, zineb and phaltan, antibiotics nystatin, oligomycin and actidione, growth regulators maleic hydrazide, 2-4-dichlorophenoxyacetic acid and indole-3-acetic acid gave promising results, although complete control was not achieved. It was noted that phaltan and actidione were phytotoxic.

In other experiments (PHELPS, 1959) finger-stalks were wounded by twisting the finger until the tissues ruptured and latex flowed out of the wound. Each injured finger-stalk was then inoculated by spraying with a concentrated spore suspension of *G. musarum*. Two days after inoculation the fruit was dipped in solutions of various fungicides or growth regulators, stored for 6 to 12 days at 54°F and then ripened at 64°F with the aid of ethylene gas. It was found that 'Shirlan' WS, zineb, 'Stop-mold' and maleic hydrazide, all at a concentration of 0·5 per cent, were the most effective treatments in reducing rot. However, all fungicidal dips caused existing peel damage such as bruises and scratches to become more noticeable. In other trials it was noted that 'Shirlan' WS provided the most consistent results and the best control; growth regulators caused delayed and uneven ripening. On the basis of these laboratory findings, a test shipment of 1 400 bunches was despatched from Colombia to Bremerhaven, Germany. Seven different dipping treatments were compared: 2,4-dichlorophenoxyacetic acid, maleic hydrazide, zineb, maneb, 'Shirlan' WS, 'Stop-mold' and control (no treatment). Apparently no significant differences were evident from the results, but it should be mentioned that there was only slight finger-stalk rot throughout the whole cargo. These

findings emphasize the all too frequent experience that laboratory expectations concerning finger-stalk rot control are not borne out under commercial conditions. It is concluded that none of the chemicals tested are entirely satisfactory in all respects (ANON., 1959), for good control is often associated with severe peel injury. There is some recent evidence that 'Dithane' D–14 may prove better than previously tested compounds.

Chemical control of finger-stalk rot has been investigated in Jamaica (MEREDITH, 1960 d) using a slightly modified laboratory technique. Uninjured, newly harvested fruit is sprayed with a dense spore suspension of *G. musarum*. The fruit is allowed to dry and the finger-stalks are then injured by flexing fingers in a manner similar to that which occurs during normal commercial handling. It is considered that spraying with conidia before wounding is more realistic than the converse order, for under natural conditions the majority of infections are caused by conidia that are already on the fruit surface at the time of reaping. After inoculation, fruit is stored at tropical temperatures for various periods prior to dipping in the test medium. It is then wrapped in perforated polyethylene bags, stored at 54° to 55°F for 12 days and finally debagged and ripened at 66° to 68°F. The first experiments to be carried out were designed to test the effect of treating inoculated fruit with nystatin at a concentration of 200 to 400 p.p.m. The results obtained were not encouraging and no significant differences were observed between treated and untreated fruit. Later, several shipments of nystatin-treated fruit were despatched to England. Once again, the reports showed that nystatin had not controlled finger-stalk rot to any significant extent.

More promising results have been obtained with 'Shirlan' WS. Preliminary experiments showed that a 1-minute dip in 'Shirlan' WS, at concentrations of 0·5, 1·0 and 1·5 per cent, gave 30, 50 and 65 per cent control respectively. However, there was slight to severe blackening of the peel at each concentration tested. In other experiments, 'Shirlan' WS treatment was followed by a rinsing in water. Here there was 15, 35 and 40 per cent control respectively; no peel injury was apparent. The efficiency of 'Shirlan' WS in the latter method of treatment is related to the length of time for which the fruit is immersed in the fungicide. A 2-minute immersion period is considerably better than shorter ones, momentary dipping being ineffective. There is no control when the period between inoculation and treatment exceeds about 24 hours. Although shipping trials are now in progress to test 'Shirlan' WS in the manner described above, insufficient data are as yet available to indicate whether it is more than moderately successful.

MAIN-STALK ROT

Nature and cause of disease

Main-stalk rot results from fungal infection of the cut ends ('butt' and 'tip') of the main-stalk (*Figure 4*). It is commonly found originating in intermediate portions of the stalk which have been bruised or split. Rotted main-stalks support a varied and extensive fungal flora, common active pathogens being *B. theobromae*, *C. paradoxa* and *G. musarum* (WARDLAW, 1935; HEIM, 1946). Secondary organisms include *Rhizopus nigricans* Ehr.,

Nigrospora oryzae (B. and Br.) Petch, *Pestalozzia leprogena* Speg., *Verticillium* (*Stachylidium*) *theobromae* Turc., and species of *Fusarium*, *Mucor*, *Aspergillus*, *Phomopsis*, yeasts and bacteria.

Figure 4. Main-stalk rot, caused by several different fungi

Because of the rapidity with which main-stalk rot progresses, serious losses may result. Rot may spread through the cushion and into the finger-stalks, thus weakening them and causing ' finger-drop '. Even if ' dropping ' does not occur, the proximal ends of the fingers may be invaded thus rendering the fruit valueless commercially.

Several methods of controlling main-stalk rot, other than those described below, have been suggested (WARDLAW and MCGUIRE, 1931 a, 1932). At harvest the main-stalk should be severed so that at least 10 inches projects beyond the distal and proximal hands. Retrimming is then carried out after inland transportation and the freshly exposed stalk tissues are thoroughly vaselined. In this way, infections that were established between harvest and loading will be eliminated and new infections will be excluded by the protective greasy layer. Other measures to reduce the extent of rot are based on the results of an extensive investigation into time and temperature factors influencing fungal growth (WARDLAW and MCGUIRE, 1932). It is suggested that there should be rapid cooling of cargoes to approximately 53°F so that fungal growth rates are depressed. It is not permissible to employ lower temperatures due to the risk of ' chilling ' fruit (WARDLAW and MCGUIRE, 1931 a). On arrival at the port of discharge fruit displaying rot should be ripened quickly, but not at high temperatures which would favour further advance of rotting.

Chemical control

The success of most methods of main-stalk treatment depends on the stem-ends remaining intact during transportation. Chemical treatment is

useless if the stem-ends are split or crushed due to subsequent rough handling, for fungi will rapidly colonize the freshly exposed, unprotected tissues.

Whatever treatment is employed, it is important that the stalk should be retrimmed and only freshly exposed, uninfected tissue treated. As a result of laboratory experimentation, TOMKINS and WOODMAN (1930) recommend coating the stem-ends with paraffin, vaseline or low melting-point fats, but these treatments have not been tested under commercial conditions. VON BECZE (1932) smeared the end of the stalk with clay and bound it with cotton-waste: finally, the stem-end was dipped into a soda solution. This provided good control but it was noted that there was some rot if the string securing the cotton-waste bruised the stalk. In other experiments it is reported that a mixture of paraffin and lanoline, with or without 5 per cent phenol, prevented rot by *C. paradoxa* and *Fusarium* spp. The use of a mixture of plaster of Paris and cement would seem to be precluded due to the lengthy period required for the paste to dry (VON BECZE, 1932).

In extensive tests carried out in Italian Somaliland, it was found that, when whole bunches were inoculated with *G. musarum* and then dipped for a few seconds in suspensions of colloidal sulphur at various concentrations, there was good control of rot (POLLACCI, CIFERRI and GALLOTTI, 1938). In addition to this treatment it was recommended that the cut ends of the main-stalks should be painted with undiluted colloidal sulphur paste. HEIM (1946) found that powdered or crystalline boric acid and 10 per cent colloidal sulphur were useful fungicides against main-stalk rot. Several organic colouring agents may also be effective (CHEVALIER and HEIM, 1937). ANDRADE, PUZZI and TORRES (1956) tested the effect of 'Shirlan' WS applied in various ways, viz. spraying or dipping the complete bunch, and spraying or brushing the cut stem-end only. For comparison, some stems were sprayed with 2 per cent 'Dowicide' A plus 1·5 per cent 'Hexamine'; on other fruit, the stem-ends were treated with 'Prinzon' or with a mixture of potassium permanganate and vaseline. The results obtained from laboratory and shipping trials were consistent in showing that the best control of rot was obtained by spraying the bunch with 0·6 per cent 'Shirlan' WS. Surprisingly, the amount of rot on stalks pasted with other fungicides was greater than that on controls. The 'Dowicide' A–'Hexamine' treatment resulted in a blackening of the fingers and gave no significant control of main-stalk rot.

In Jamaica a fungicidal paste containing polyethylene polysulphide (PEPS) and mercaptobenzothiazole has been used with some success for several years. PEPS is also used by the United Fruit Company in Central and South America (ANON., 1959). Stalks of West African bananas destined for the United Kingdom market are treated with a lime paste (Elders and Fyffes Ltd, 1958).

Another approach to main-stalk rot control is the use of protective caps, made of wood, metal or other materials, which are placed over the severed stem-ends. It has been suggested that a metal cap containing a fungicide-soaked sponge could be fixed over the cut end and retained there during transport (ANON., 1949 b).

In proposing any particular treatment for main-stalks it is important to consider the time and skill required to carry it out. An observer at a wharf

in Jamaica, for instance, is immediately impressed by the large numbers of bunches which have to be handled in a relatively short time. It is essential, therefore, that any form of stalk treatment should be simple and quickly executed. Because of this it seems unlikely that protective caps or mixtures which take some time to dry will come into general use.

' BLACK-END ' AND ' SQUIRTER ' DISEASE

Nature and cause of disease

(1) ' *Black-end* '—In Australia the bunch after harvest is usually divided into individual fingers (' singles ') which are then packed and transported overland in wooden crates. A condition known as ' black-end ' may be very troublesome because of the unattractive appearance of affected fruit: the actual loss from decay and inedibility is negligible (SIMMONDS and MITCHELL, 1940). ' Black-end ' is a decay of the severed finger-stalk and adjacent part of the finger, and first becomes noticeable towards the end of the ripening process. HOETTE (1935) showed that the disease can be caused by one or more of four fungi, viz. *G. musarum*, *Fusarium* spp., *Nigrospora musae* McL. and H. [*N. sphaerica* (Sacc.) Mason] and *C. paradoxa*. *G. musarum* is considered the most important fungus due to its relatively high pathogenicity and the high frequency with which it is associated with ' black-end '. Infection by these fungi is initiated by spores which germinate on the severed stalk tissues. Accounts of detailed studies on ' black-end ', with special reference to *G. musarum*, are given by HOETTE (1935) and by SIMMONDS and MITCHELL (1940).

(2) ' *Squirter* ' *disease*—This disease also may cause serious damage to bananas in Australia and it is commonly associated with ' black-end '. It is known to be caused by a species of *Nigrospora*. SIMMONDS (1933) has referred it to *N. sphaerica* but MCLENNAN and HOETTE (1933) describe it as a new species, *N. musae*.

Symptoms of ' squirter ' disease do not usually become apparent until the ripening room stage. Infected fingers often appear sound externally and only in severe cases is the peel discoloured a bluish-black. However, on cutting the fruit, the pulp is found to be decomposed, brown and semi-liquid. If the fruit is squeezed, the pulp may ' squirt ' out of the stem-end or from the side. MCLENNAN and HOETTE (1933) demonstrated that the fungus normally gains entrance to the fruit through the exposed vascular strands in the finger-stalk. WARDLAW (1935) gives a summary of the essential features of the investigations into ' squirter ' disease carried out up to 1935.

Chemical control

Much work has been done in Australia to formulate control measures for ' black-end ' and ' squirter '. Initially, it was shown that the immersion of fruit as singles in a 1 per cent suspension of ' Shirlan ' AG *before* packing gave complete control of ' squirter ' (SIMMONDS and MITCHELL, 1937, 1940). Only moderate control of ' black-end ' occurred when decay was due to *G. musarum* but, when it was mainly of the *Nigrospora* type, good control was obtained. Apparently, adoption of this procedure by growers was very slow

owing to its tediousness. A more acceptable method was introduced by MAGEE, EASTWOOD and FOSTER (1939). A series of experiments was designed to test the efficacy of dipping the fruit in cases, *after* packing for market in the usual manner. In this way, complete control of ' squirter ' was obtained and ' black-end ' was practically eliminated. Trials using 0·5 per cent ' Shirlan ' AG were also made, and again the degree of control of both diseases was satisfactory. Under commercial conditions it is suggested that cases of fruit should be lowered and raised a few times in the dipping medium to ensure the removal of air-locks: the total time of dipping need not exceed 30 seconds. An important feature of this work is that good control is still obtained even when the interval between packing and dipping is about 24 hours. This indicates that case-dipping could be carried out at a central depot before despatch to market.

In later experiments MAGEE (1939) obtained improved control of ' squirter ' and ' black-end ' by substituting the water-soluble ' Shirlan ' WS for ' Shirlan ' AG. The former leaves no deposit on the fruit and is apparently more economical. It is important to use a ' wetter ' such as ' Agral ' 2, and 2 oz ' wetter ' to 0·5 lb fungicide is recommended. A third preparation known as ' Shirlan flakes ', in which sodium salicylanilide is combined with a ' wetter ', was also shown to give improved control (MAGEE, 1941).

A regulation was brought into effect in 1949 prohibiting the sale of bananas in New South Wales between 1 May and 30 November in any year unless treated with a fungicide containing salicylanilide (ANON., 1949 a). The choice of fungicidal preparation, that is, ' Shirlan ' AG, ' Shirlan ' WS or ' Shirlan flakes ', is optional. O'NEILL (1949) describes a simple field test to detect the presence of salicylanilide on the banana fruit peel. Since the introduction of legislation governing control measures, it is reported that ' squirter ' and ' black-end ' have been practically eliminated (ANON., 1951, 1953).

Trachysphaera FRUIT-ROT

Nature and cause of disease

Trachysphaera fructigena was originally described by TABOR and BUNTING (1923) as an organism causing pod diseases of cocoa and coffee in the Gold Coast. In recent years the fungus has caused serious damage to bananas growing in West Africa (BRUN, 1954; THOROLD, 1956), to which area it appears to be restricted (*C.M.I. Distribution Map No. 249*). In the field *T. fructigena* causes symptoms similar to those of ' cigar-end ' disease caused by *Verticillium* (*Stachylidium*) *theobromae* (BRUN, 1954). BRUN and MERNY (1947) observed a new form of rot on ' Gros Michel ' fruit that was shipped from West Africa to Dieppe. This form of rotting is, at certain times of the year, common on fruit from the British Cameroons and Fernando Po (MEREDITH, 1960 a). Rotting is not of the typical ' cigar-end ' type, for infection occurs more or less at random along the finger. Early stages of infection of green fruit are characterized by a buff-yellow or khaki discoloration of the peel. During the ripening process, rotting spreads rapidly and the skin turns dark brown or black and is thrown into folds (*Figure 5*). Eventually the complete finger may be affected, presenting a mummified

appearance: masses of conidiophores and conidia develop on the surface of necrosed tissues. The inner pulp generally dries out and becomes tough and leathery.

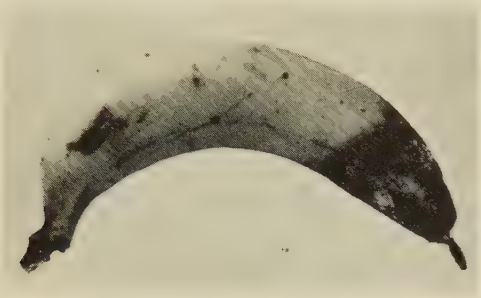

Figure 5. Banana fruit-rot caused by T. fructigena

BRUN and MERNY (1947) and MEREDITH (1960 a) have demonstrated the rapid progress of infection by *T. fructigena* following wound-inoculation of green bananas. The former workers also report that they were able to infect apparently unwounded fruit.

Chemical control

There appears to be no information in the literature about measures for controlling storage rot caused by *T. fructigena*. However, the serious proportion sometimes assumed by wastage of this type (Elders and Fyffes Ltd, 1959) would appear to warrant more detailed studies on the etiology of the disease. If the majority of infections take place after harvest, as with *Gloeosporium* rots, then some form of post-harvest chemical treatment may be effective. On the other hand, such treatment is unlikely to control the disease if it is initiated before reaping.

There is a risk of healthy fruit becoming infected in the ripening rooms. Thus, some observations in the United Kingdom suggested that infection of Jamaican ' Lacatan ' bananas was caused by spores of *T. fructigena* that were introduced into the ripening rooms on a previous consignment of heavily infected Cameroon ' Gros Michel ' fruit (MEREDITH, 1960 a). Thorough disinfection of ripening rooms between successive consignments of fruit may reduce the risk of cross-contamination.

OTHER FRUIT-ROT FUNGI

B. theobromae sometimes causes localized lesions on fingers that have been mechanically injured (*Figure 6*). Many other fungi have been recorded as being associated in a primary or secondary capacity with various forms of fruit-rot (WARDLAW, 1935). Examples include *Oidium lactis* f. *musarum*, *Fusarium semitectum* var. *majus*, *Verticillium albo-atrum*, *V. candelabrum*, *Cercospora* spp., *Helminthosporium sacchari*, *Cephalothecium roseum*, *Pestalozzia leprogena*, *Nigrospora* spp., *Acrothecium lunatum* and *Rhizopus nigricans*.

DISCUSSION AND CONCLUSIONS

From this review it is clear that the study of chemical control of banana fruit-rot is still in an early stage. Nevertheless, it is encouraging that ' squirter ' disease and ' black-end ', which were formerly very serious to the Australian trade, are now under complete control commercially due to compulsory treatment with ' Shirlan '. Good control of main-stalk rot is also

Figure 6. Lesions on fingers caused by B. theobromae

being obtained elsewhere, due to the use of various fungicidal pastes. On the other hand, studies on chemical control of anthracnose (' non-latent ') and finger-stalk rot have not yet progressed beyond the experimental stage.

Although ' Shirlan ' completely controls ' black-end ', it provides only moderate to good control of finger-stalk rot. Both rots originate through infection by *G. musarum*, *Fusarium* spp. and other fungi of wounded finger-stalk tissues. When a finger-stalk is bent or twisted the tissues often rupture in a manner shown in *Figure 7*(a). On releasing the mechanical strain, tissue

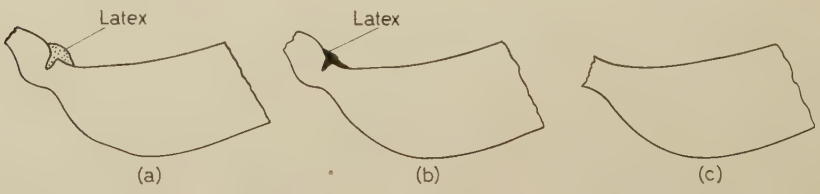

Figure 7. Diagrams illustrating injury to finger-stalks: (a) *Wound caused by bending finger while attached to main-stalk;* (b) *Wound closed after release of strain;* (c) *Completely severed fingerstalk*

tensions cause the finger to resume its original orientation so that the wound tends to close [*Figure 7*(b)]. Fungal spores on the surface of the finger-stalk may enter the wound and come to lie in a relatively deep-seated position. The presence of latex and minute air-locks in the wound will hinder entry of externally applied solutions. In this way, the fungus may escape fungicidal action and so infect the tissues. With ' single ' bananas there will be a

more direct contact between fungicide and severed tissues [*Figure* 7(c)], possibly accounting for the improved control.

G. musarum is responsible for a considerable proportion of the total fruit-rot on bananas exported from the major growing areas. In a primary capacity it is associated with anthracnose (' latent ' and ' non-latent '), finger-stalk rot, main-stalk rot and ' black-end '. In the plantations the fungus sporulates abundantly on dead or dying banana leaves and bracts. SIMMONDS and MITCHELL (1940) found that removal of this ' trash ' resulted in a significant reduction of ' latent ' anthracnose and ' black-end '. This finding should encourage growers to maintain a high standard of plantation hygiene in order to minimize the inoculum source. The undesirability of allowing ' trash ' leaves to come into contact with harvested fruit has been discussed.

Although this review has emphasized chemical control measures it is still essential that every attention be given to the recommendations of WARDLAW and co-workers. In fact any form of chemical treatment will be supplementary to careful handling, rapid loading and speedy cooling of fruit for export.

SUMMARY

The major forms of storage rot of banana fruit are briefly described and the literature relating to their control by chemical means is reviewed. It is concluded that this field of research is, with few exceptions, still in the experimental stage and that further investigation is necessary before methods of commercial treatment can be recommended with confidence.

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Root Nodulation and Agricultural Potential of the Leguminous Genus Psophocarpus

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Field observations (Masefield, 1957) have already established that the tropical legume *Psophocarpus tetragonolobus* has an exceptional capacity for forming very large and numerous root nodules, which might make it of agricultural interest. It was considered desirable to obtain further information and to examine other species of the genus to see whether they had the same capacity.

On the available evidence, the genus Psophocarpus consists of eight species. One of these, *P. tetragonolobus*, appears to be a cultivar since it has not been recorded as a truly wild plant in any country. The remainder are all plants native to tropical Africa. For comparative studies, it was only possible to obtain seed of three species. Seeds of *P. tetragonolobus* and *P. lukafuensis* were collected respectively in Malaya in 1956 and in Northern Rhodesia in 1960. Seed of *P. palustris* was kindly supplied by Mr H. D. L. Corby, Grasslands Research Station, Southern Rhodesia, from a collection made in Portuguese East Africa; a few seeds from the Royal Botanic Gardens, Kew, were also sown to establish the identity of species. These three species are representative of the range of size in the genus.

Before describing the experimental results, it will be desirable to provide notes of each of the species concerned:

P. tetragonolobus is occasionally cultivated as a garden vegetable, particularly in southern Asia. The green pods are cooked, and in some cases the tuberous roots are also used as food. The plant goes under a number of common names: winged bean, four-angled bean, Goa bean, Manila bean, princess bean, asparagus pea. Some of these names are also used for other legumes with winged pods. In particular, confusion should be avoided between this species and the genus Tetragonolobus, one species of which, *T. purpureus*, has been introduced from north Africa to England under the name of asparagus pea as a vegetable.

The plant is naturally a climbing perennial, but is usually grown as an annual in rows with sticks or a trellis to support it. The roots are rather numerous, with the main laterals running horizontally for several feet at a shallow depth below the surface. These laterals with time thicken and become storage organs. Such thickening does not take place in the first few months; it has only been personally observed to start in plants ten months old. This characteristic is common to the other species.

P. palustris is very similar to *P. tetragonolobus* in habit and morphology, but the leaves and whole plant are somewhat smaller. It has occasionally been used as a cover crop on rubber estates in Indonesia.

P. lukafuensis is very much smaller than the other two species. In Northern Rhodesia it grows in open grassland on seasonally wet sites near the edges of swamps, twining round the stems or leaves of grasses.

EXPERIMENTAL RESULTS

As only very small quantities of seed, with a germination capacity of 30 to 40 per cent, were available for each species, observations were limited to a small number of plants, which were grown in a tropical greenhouse at the Oxford University Field Station.

P. tetragonolobus was grown during preliminary trials in the summer, either in the open or in two greenhouse sections with respective temperatures of approximately 65°F and 80°F. Of the seed sown in the open, only 2 per cent germinated and the plants only grew to a height of from 5 to 9 in. At 65°, the plants were still very stunted, but at 80° they made rapid and normal growth without, however, ever flowering. To discover if short days would induce flowering, plants were grown in the winter at the same temperatures. There was no flowering, and growth was very slow, presumably due to the low level of solar radiation. Uninoculated plants in this series failed to form nodules, with the exception of one plant which formed two, probably by contamination from neighbouring inoculated plants.

For a more detailed examination, 5 plants were grown singly in 10 in. earthenware pots filled with a loam soil. The soil was inoculated by thoroughly mixing with it approximately 0·75 g per pot of finely ground dried nodules derived from plants previously grown at the Field Station; the original inoculum was obtained in the same way from nodules collected in Malaya. A bamboo stake was placed in each pot to support the growth of the plant. The pots were placed in the hotter section of the greenhouse, where minimum temperatures were not allowed to fall below 75°F or 80°F at different periods, but the maximum rose to as much as 100° on sunny days. The plants were removed from the pots at a mean age of 109 days from sowing, and the root systems washed out and examined. Mean data obtained are shown in *Table 1*.

Table 1. Mean results of observations on Psophocarpus spp.

	P. tetragonolobus	P. palustris
Fresh wt (g) of one plant	585·1	198·5
Fresh wt (g) of nodules per plant	23·12	2·03
No. of nodules per plant	627	35
Crude protein percentage on dry matter of shoot	25·62	11·70

The results for number and weight of nodules are exceptionally high, and fully confirm the previous finding; so far as is known, the weight of nodules per plant is the highest ever recorded for any annual or perennial legume in the first few months of growth. For comparison, plants of

Phaseolus vulgaris, which nodulates freely, averaged 1·55 g of nodules per plant when grown in pots of the same size; dwarf peas (*Pisum sativum*) averaged 0·41 g per plant. The nodules of *Psophocarpus tetragonolobus* in this experiment were of a large mean size; the largest single nodule weighed 0·60 g with an extreme diameter of 1·2 cm. For all the nodules examined, the internal tissues were coloured red.

The mean crude protein content for the shoots of these plants is also high, since it slightly exceeds mean data for any of the common tropical legume fodders given in lists by WALSH (1958) or by WILSON and LANSBURY (1958).

P. palustris was also found in a preliminary test to grow best in the hottest section of the greenhouse. For a more detailed examination, 5 plants were grown singly under the same conditions as described for *P. tetragonolobus*. As no inoculum of Rhizobium originating from this species was available, each pot was inoculated with a mixture of dried ground nodules from (a) *P. tetragonolobus*, and (b) *P. palustris* originally inoculated with *P. tetragonolobus* material; to which was added some Northern Rhodesian soil in which plants of *P. lukafuensis* were found growing.

The plants were removed from the pots and examined at 106 to 107 days from sowing. It will be observed from *Table 1* that the weight of a plant is only about one third of that of *P. tetragonolobus*. The number and weight of nodules is within the normal range for legumes of this size and not outstandingly high. The nodules were again fairly large; the largest single nodule weighed 0·23 g and was 1·0 cm in diameter. Only a few of the larger nodules had red tissues. The crude protein content of the shoots was only 11·7 per cent, which contrasts with a value of 23·3 per cent for some of the plants grown in preliminary tests.

It is of course arguable, though not certain, that nodulation in this species would have been greater if it had been possible to inoculate with a strain of Rhizobium from the species itself.

Five plants of *P. lukafuensis* were grown in the same way as for the two preceding species, and were inoculated with dried ground nodules collected from this species in Northern Rhodesia. Though the initial growth was good, further development was arrested and clearly the conditions were unfavourable and no conclusions can be reached. It is therefore necessary to fall back on such cursory examination of nodulation as was made on wild plants in Northern Rhodesia. Here it was impossible to excavate entire root systems in the grass swards in which *P. lukafuensis* grows, and no facilities were available to weigh the plants. The species appeared to nodulate rather abundantly, and with fairly large nodules, for a legume of its size.

DISCUSSION

It seems clear from these observations that *Psophocarpus tetragonolobus* is the species of the genus which should first be subjected to further examination for potential agricultural use. The high capacity for nodulation, at least under favourable conditions, also warrants further study.

This species appears to have a potential usefulness in four capacities: as green manure, cover crop, fodder crop and regenerative fallow. Its climbing habit is certainly not ideal for any of these uses; however, this

habit is common to several other legumes which are used in the capacities suggested, and has not prevented *P. palustris* being used in practice as a cover crop. Perhaps the most intriguing possibility is in the possible use of this species as a regenerative fallow. If grown for two or three years, there should be an extensive development of the tuberous roots at a shallow depth in the soil. This is an unusual combination with a leguminous crop. It must be emphasized, however, that *P. tetragonolobus* seems unlikely to have any marked drought resistance, and should probably be grown as a perennial only in the wet tropics.

Since first drafting this paper, my attention has been drawn by Professor Purseglove to the following statements by THOMPSTONE and SAWYER (1914) about *P. tetragonolobus* in Burma, where the plant is known as *pe-myit*: 'In some soils the development of bacterial nodules is extraordinary; the nodules are very large and the Burmese say that they are more plentiful when the plant is grown on land which has remained fallow for one or more years. A crop of tubers which is covered with these nodules is regarded with a certain amount of suspicion and is not altogether a success from a popular point of view. The cultivator, therefore, precedes his *pe-myit* with a crop of paddy. A very common rotation, especially in Kyaukse District, is, first year paddy, second year *pe-myit*, third year sugar-cane, which is sometimes ratooned. The last crop is said to give a 50 per cent better yield if preceded by *pe-myit*. The cost of cultivation of this bean is heavy . . . The yield of roots varies . . . In Kyaukse District, where the prices are generally low, the cultivator looks to the succeeding sugar-cane crop for his profits. In Mandalay where sugar-cane is not grown there is a good market both for the roots and the immature pods.' These remarks certainly strengthen the suggestion of a rotational benefit to be obtained by growing *P. tetragonolobus*.

Those who might like to experiment further with this species should be warned that seed is scarce and usually only obtainable in very small quantities. It is most likely to be obtained from countries of southern and southeast Asia, such as India, Burma, Ceylon and Malaya. *P. tetragonolobus* may be presumed, until further evidence is available, to belong like most tropical legumes to the cowpea cross-inoculation group; and field observations suggest that it will form some nodules on most tropical soils, even virgin forest ones. It is possible, however, that maximum nodulation will not be attained, especially with a first crop, without inoculation.

SUMMARY

Further observations on *Psophocarpus tetragonolobus* confirm that this species has, under favourable conditions, an exceptional capacity to form a very large number and weight of root nodules. Other species of the genus examined do not appear to have this capacity to the same extent.

It is suggested that *P. tetragonolobus* is well worthy of trials to assess its value as a green manure, a cover crop, a fodder crop, or a restorative 'fallow' crop, particularly in the wet tropics.

ACKNOWLEDGEMENTS

The author is indebted to Professor G. E. Blackman, for his continued interest in these investigations; to members of the Northern Rhodesia

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Nutrient Imbalance in Sugar-cane as Revealed by Foliar Analysis

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This investigation was undertaken to shed some light on an unexplained scorching of cane leaves which occurred fairly extensively in the Clark–Rochard area of Southern Trinidad in August and September, 1959. As the investigation progressed, it became apparent that the scorching was associated with the practice of applying sulphate of ammonia predominantly, and almost exclusively, for fertilizing canes in that area. The main soil types around Clark–Rochard are Rochard sandy clay loams, Moruga clay loams, and La Fortune clay; they have, on the basis of soil analysis, from medium to high potassium contents.

METHODS

The cane plants were four months old ratoons and the third fully opened leaf was selected for analysis. Two composite samples were taken from areas showing the scorching symptoms, and two samples from areas without symptoms but adjacent to those showing symptoms. After drying and grinding, samples were analysed for nitrogen, phosphorus, potassium, calcium and magnesium. Nitrogen was determined colorimetrically after a modified Kjeldahl digestion. Phosphorus was determined colorimetrically on a perchloric–nitric acid digest. Potassium was determined flame-photometrically on the perchloric–nitric acid digest, while calcium and magnesium were determined on the perchloric–nitric digest by complexometric titration with (ethylenedinitrilo) tetra-acetic acid.

RESULTS

The analytical data are presented in *Table 1.*

Table 1. Four months old ratoons (third leaf): values as % dry wt

Element	N	P	K	Ca	Mg
Canes with symptoms (1)	2·1	0·23	0·85	0·30	0·24
Canes with symptoms (2)	2·1	0·24	0·92	0·30	0·21
Mean	2·1	0·23	0·88	0·30	0·22
Canes without symptoms (1)	1·9	0·26	1·25	0·25	0·15
Canes without symptoms (2)	2·0	0·23	1·20	0·21	0·11
Mean	1·95	0·24	1·22	0·23	0·13

DISCUSSION

Although data on the critical levels of nitrogen, phosphorus and potassium in sugar-cane are not yet available for Trinidad, data from other cane-growing areas may be used with profit until such information is available. In Mauritius (CRAIG, 1938, '39, '40, '41, '44), nitrogen is regarded as excessive when it rises above 1·85 per cent (third leaf of 5 to 7 months old ratoons), while in Jamaica (INNES, 1956), 1·83 per cent nitrogen (third leaf) is regarded as a satisfactory level for ratoons at 5 months. It is very probable, then, that the mean value of 2·1 per cent nitrogen found for canes with symptoms (*Table 1*) in this investigation is high. Insofar as phosphorus is concerned, data quoted by EVANS (1955), INNES (1951), SAMUELS *et al.* (1955) indicate that the mean phosphorus content of the samples analysed in this work is within normal limits. Concerning potassium, work in Mauritius (CRAIG, 1938, '39, '40, '41, '44), Jamaica (INNES and CHINLOY, 1951) and British Guiana (EVANS, 1955) has shown that levels below 1·00 per cent potassium are associated with deficiency. It would therefore appear that the scorching under study was due to potassium deficiency. The deficiency was, very likely, induced by the high nitrogen values reported in *Table 1*, a view which is supported by knowledge of the fertilizer practices employed and by the following:

(*1*) The leaf scorching was identical with colour plates of potassium deficiency given by MARTIN (1938).

(*2*) SAMUELS *et al.* (1955) quote very similar data for nitrogen-induced potassium deficiency in Puerto Rico: N = 2·13; K = 0·87 per cent.

(*3*) *Table 1* shows that there was increased calcium uptake at the higher nitrogen levels and that the higher magnesium values are associated with low levels of potassium. These data are consistent with the findings of EVANS (1955) who found that sulphate of ammonia promoted calcium uptake and that high magnesium values were associated with low levels of potassium.

It has been suggested from the results of soil analyses that additional potassium is not required in Trinidad soils with potassium levels greater than 50 p.p.m. for sands and 75 p.p.m. for clays. This work would indicate that this premise needs re-examination.

SUMMARY

The results of an investigation into a previously unexplained scorching of sugar-cane leaves are presented and discussed.

The scorching is attributed to nitrogen-induced potassium deficiency.

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Transplanting Papaya versus Seeding in Place

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Throughout the world various methods for propagating papaya have been recommended. In Tanganyika, new groves are established by transplanting seedlings or, more commonly, by seeding directly in the field which according to Greenway *et al.* (1953) produces stronger more even stands than transplanting. They state that transplanting risks seed-bed injuries as well as drying and twisting of the roots. In southern Queensland (Agnew, 1954), papaya plants are usually transplanted; but seeds are frequently sown in the field and covered with a light mulch at a time when weather conditions are favourable for rapid germination. In Florida, plants are transplanted from small pots to the field (Harkness, 1955). It would not be possible to review recommendations for all papaya-growing areas, but enough is cited to show that papayas are planted commercially both by seeding and by transplanting.

In Hawaii, papaya seedlings are generally transplanted to the field at six weeks to six months of age. Seedlings held too long are frequently pot-bound and develop into unthrifty trees (*Figure 1*). An exception to the usual practice of transplanting is found in the Puna area, where seeds are generally planted in place in small soil-filled pockets in the lava rock. Although it cannot be attributed solely to the method of propagation, the frequency of curved trunks in Puna papaya groves is low.

Occasional young volunteer seedlings found in commercial papaya orchards have been observed to have straight tap roots difficult to extract by hand, whereas transplants rogued at flowering were easily removed, frequently with one hand. The following investigation compares, in terms of plant growth and yield, transplanting seedlings with seeding in place.

MATERIALS AND METHODS

Greenhouse experiments

In three experiments, twenty to fifty 12-ounce cans of soil were planted with 3 to 5 Line-8 Solo seeds per can. The same day ' 4 leaf stage ' seedlings (*Figure 3*) were transplanted to a similar number of cans of soil. The seedling was placed in a $2\frac{1}{2}$ in. cone-shaped divet in the soil and the soil was then firmed around the seedling. Eight to twelve weeks later, plants were removed from the can and the root systems classified as to whether looped or straight (*Figure 2*).

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* Formerly Assistant Horticulturist, Hawaii Agricultural Experiment Station. Grateful acknowledgement is made for the facilities provided by the University of Hawaii and for the assistance of its staff.

Figure 1. One-year-old Solo papaya showing high frequency of curved trunks typical of transplanted fields observed in windy areas

Field experiments

Line-8 Solo, a strain of the Solo variety, was used as a plant material representing a commercial type. In separate experiments a non-commercial selection (No. 23)*, which is a low-bearing and fast maturing papaya, was also used in order to shorten the experimental time and to evaluate the planting methods with a papaya plant of different growth habit.

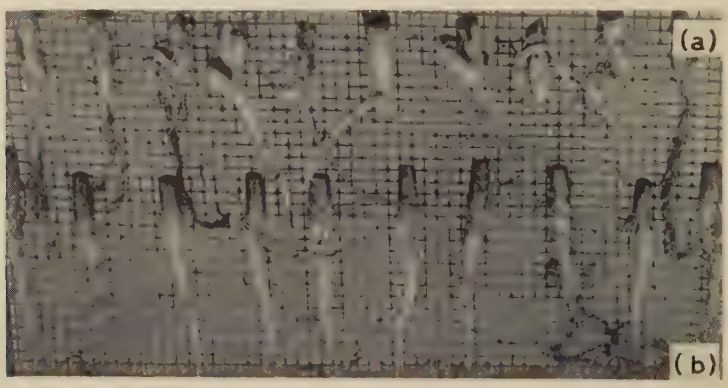

Figure 2. Three-month-old tap roots of papaya which had been transplanted into 12 oz. cans at the four-leaf stage (a), *and those seeded in 12 oz. cans* (b)

Large flat cans were used as community pots for the ' twice transplanted '. Each of these cans contained a base of coarse No. 0 grade vermiculite over which about three hundred seeds were spread between two thin layers of No. 2 grade vermiculite.

Twelve-ounce cans with drainage holes in the bottom and 3 in. × 3 in. × 4 in. black paper bands in gravel-drained flats were used for individual containers.

No. 2½ cans having both ends removed and the top replaced by a 0·015 in. polyethylene film were used for individual ' germination hoods ' in the field (*Figure 3*).

* Seed supplied by Dr H. Y. Nakasone, Hawaii Agriculture Experiment Station.

Temperature was recorded by a Dickson Minicorder thermograph with probe.

Seeds with gelatinous cover removed were started in community pots, individual containers, and in the field on the same day. Seeds planted in community pots and those planted in individual containers were covered with a shallow layer of No. 2 vermiculite kept just moist to the touch. Three weeks after seeding, strong young seedlings were transplanted from the community pots in the commercially accepted practice using individual 12-ounce

Figure 3. (a) *Papaya seedlings seeded in place under 'individual germination hoods' at thinning stage, i.e. 21 days from seeding;* (b) *Same seedlings, hood removed;* (c) *Papaya seeded in place at 7 weeks from seeding, growing up through clear polyethylene (0·015 in.) top previously cut at 21 days;* (d) *Papaya seedlings, left to right at 4 days, 3 days, 2 days and 1 day after germination, grown in vermiculite in the greenhouse. Note the length of roots of the 1 and 2 day old seedlings in centimetres*

containers of the same kind as those used in previous direct seedings. At about six to eight weeks, these 'twice transplanted' seedlings and the 'single' seedlings were transplanted in a random pattern into the field. Growth measurements were then taken at various intervals up to flowering.

Seedlings transplanted once will be designated hereafter as ' single transplanted ' and those transplanted twice, ' twice transplanted ', while those seeded in the field will be designated ' seeded in place '.

RESULTS AND DISCUSSION

Greenhouse experiments

In three experiments ' looped ' and twisted roots resulted from transplanting old seedlings (4 leaf stage). *Table 1* shows a consistently higher percentage of straight tap roots in three experiments performed over a period of several months.

Figure 2 shows roots and lower stems of three-month-old seedlings from Experiment I (*Table 1*). The bottom row of tap roots represents plants

Table 1. Effect of seeding Line-8 Solo papaya in place versus transplanting at 4 leaf stage from a community pot into 12 oz. cans. The numbers of straight and looped roots were counted at 2 to 3 months of age

Treatment	*Percentage of straight tap roots*		
	Expt I	*Expt II*	*Expt III*
Transplanted	12·0	38·0	23·0
Seeded directly	100·00	98·5	99·7

seeded directly into 12-ounce cans while those in the top row were from plants which had been transplanted as small seedlings in the 4 leaf stage. Plants of this age are commonly used in transplanting papaya. The 4 leaf stage [*Figure 3* (d)] was chosen in these experiments to demonstrate the effect of poor transplanting technique.

Experience has indicated that if papaya seedlings are transplanted into containers before the tap roots exceed 5 cm [*Figure 3* (d), 2–3 day old], good plants can be obtained. At this stage, the seedling has just straightened and the primary leaves expanded. By the time the secondary leaves are easily visible, transplanting may result in considerable set-back and a high percentage of twisted and/or looped roots, particularly when the long roots are forced into a shallow divet. Cool temperature* will cause larger roots in comparison to the top and may thereby require taking the seedling at a smaller stage of above-ground growth. When a tree with a looped, twisted, or unbalanced root [*Figure 4* (a)] approaches fruiting maturity, it may frequently have a curved trunk (*Figure 1*). Leaning trees of this type may interfere with cultural practices and are easily blown over by the wind during storms. Although many times the fruit is easily picked, yields may be low.

Field experiments

Plants grown in the generally accepted manner of transplanting from community flats to cans and eventually to the field (' twice transplanted ') were compared with seeding directly in the can (' single transplanting ') and seeding directly in the field (' in place seeding ') in the following experiments:

* Unpublished data.

Experiment I—Line-8 Solo seeds were seeded on 23 September 1956, in community pots, in 12-ounce cans, and in the field, covered with vermiculite only. The transplants were transferred to the field at about 7 in. (18 cm) height. At six weeks, those seeded directly in the cans [*Figure 5* (e)] were about twice the size of field germinated plants [*Figure 5* (f)] and four times the size of the seedlings transplanted from community cans [*Figure 5* (d)].

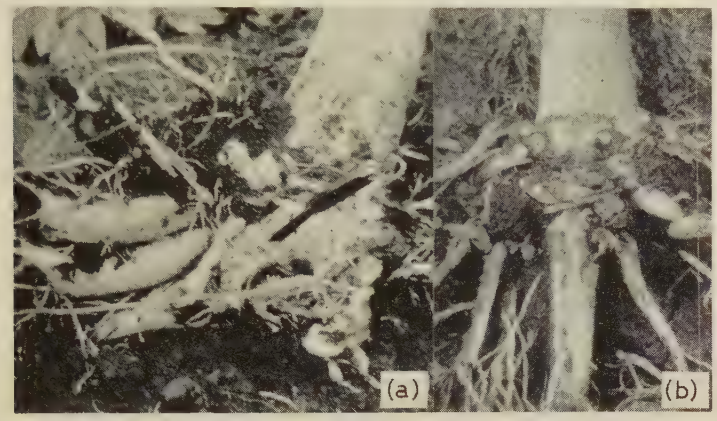

Figure 4. (a) *Main roots of a nine-month-old plant with crooked trunk, typical of improperly transplanted seedling. Size can be seen by the jack-knife sticking in the malformed stunted tap root;* (b) *nine-month-old seedling showing the straight tap root and trunk, typical of plants resulting from direct seeding*

The single transplanted seedlings were placed in the field at six weeks of age, whereas the twice planted seedlings were planted in the field three weeks later because of the small size at six weeks of age [*Figure 5* (d)]. At six weeks of age, the seedlings planted in place [*Figure 5* (e)] were somewhat larger and more vigorous than the twice transplanted seedlings [*Figure 5* (d)].

Table 2. Comparison of propagation methods for Line-8 Solo papaya as measured by height and date of flowering

Treatment	*Average height, cm, at*			*Average date of flowering*	*Average days in field to flowering*
	3·5 mos	*5 mos*	*flowering*		
(*1*) *Twice transplant*	35·7	69·3	129·7	*11 May 57*	169
(*2*) *Single transplant*	66·3	103·3	147·5	*15 Apr 57*	161
(*3*) *Seeded in place*	80·2	136·7	155·8	*1 Mar 57*	160
LSD 0·05	13·1	17·6	10·2		
0·01	18·6	25·1	14·4		

At five months, representative plants of each treatment were measured, removed and photographed [*Figure 5* (a), (b), (c)]. *Table 2* compares heights at $3\frac{1}{2}$ to 5 months. Seeding ' directly in place ' produced a tree nearly twice as big at five months as double transplanting; it also produced flowers two months earlier. The average height at flowering was 26·1 cm lower in the ' twice transplanted ' than with the ' in place ' tree (with Line-8 Solo).

Although this experiment was conducted during winter months, the trees seeded in place surpassed the single transplants in growth, despite the 'seeded in place' trees being smaller at the time the transplanted trees were placed in the field [*Figure 5* (f), (e)].

Figure 5. Line-8 Solo papaya plants at 5 months of age: (a) *Twice transplanted;* (b) *Single transplanted;* (c) *Seeded in the field. Line-8 Solo papaya seedlings at age 6 weeks;* (d) *Transplanted from community pot into can;* (e) *Seeded directly in the can;* (f) *Planted directly in the field*

The average number of days in the field to flowering was essentially the same for all three methods, i.e. 160 to 169 days.

Experiment II—The above experiment was repeated during the summer of 1957 with an early-flowering, dwarf-type papaya (selection No. 23). Seeds were planted 13 July 1957 by the same method as before, except that those seeded in the field were covered with No. 0 vermiculite which had been soaked in nutrient solution and they were subsequently covered with small plastic greenhouses made in various ways.

The individual 'germination hood' technique gave an 80 to 100 per cent stand, depending on the type of hood used. Solid plastic commercial hot caps used for early vegetables in temperate climates were not effective because of excessive heat built up during the experiment (130° F during bright sunny days and 100° during intermittently cloudy days). Under

polyethylene-covered gallon cans (both metal ends removed), the maximum daily temperature averaged 110°F during the day with 70°F night temperature. Outside air temperature averaged 85°F during the day and 70°F at night. On 9 September 1957, the double and single transplants were set out. The ' doubles ' were only slightly smaller than the ' singles '. The ' seeded in place ' trees were about twice the size of the transplants. The difference in relative size from the preceding experiment may have been due to the different variety used or to warm summer night temperatures. The double transplants were of two types, those transplanted from cans of vermiculite and those transplanted from paper bands of soil. *Table 3* and *Figure 6*

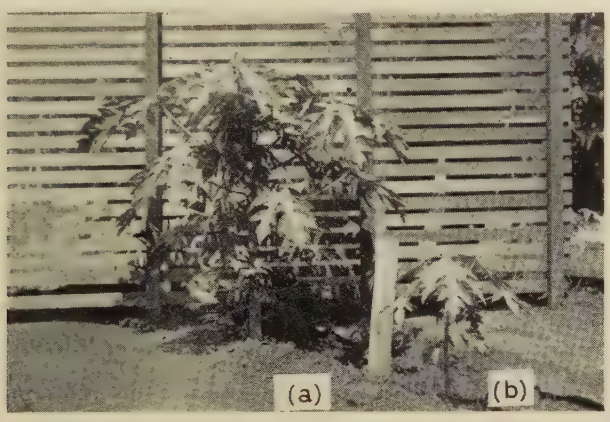

Figure 6. Seedlings of early maturing selection (dwarf type) papaya at age 3 months showing the difference between (a) *seeding in place and* (b) *transplanted seedling*

present the difference in growth at three months of age. These results support the previous experiment using Line-8 Solo seedlings, with the exception that single transplants were not significantly better than double transplants when both were germinated and grown in nutrient-fed vermiculite. Trees seeded directly in place were nearly double the size of the best transplanted tree (*Figure 6*) and flowered in less than three months, whereas those twice transplanted flowered at about four months from seed. In the field the time to flower was one month longer for ' direct ' seedage with this dwarf Solo type which flowered in 51 to 81 days as compared with 160 to 169 for Line-8 Solo.

Experiment III—On 28 October 1957, a 0·6 acre planting of Line-8 Solo papaya seeded in place at Poamoho (using size 2½-pound cans open at both ends and covered with clear polyethylene) gave an 87 per cent stand with only one tree planted per location. Had the standard practice of two trees been used, it is quite likely that less than 4 per cent of the locations would have been missing a tree. The spacing was an alternating 6 ft × 6 ft × 10 ft double row planting allowing 910 trees per acre. The last weed spraying was carried out just before cutting the plastic tops of the cans covering the seedlings. At this time the papayas had developed their first true leaves. Cans

Table 3. Comparison of propagation methods for a dwarf Solo (No. 23) papaya as measured by height, diameter, height to first flower and date of flowering

Method of propagation	3 months		4 months		Height to first flower cm	Date of first flower	Days in field to flowering
	Height cm	Diameter cm	Height cm	Diameter cm			
(1) 'Twice' in vermiculite	20·7	0·8	57·3	2·5	53·7	1 Nov 57	53
(2) 'Twice' in soil (bands)	29·3	1·1	70·0	3·2	60·7	27 Oct 57	48
(3) Single in vermiculite	23·1	0·9	60·5	2·5	54·7	30 Oct 57	51
(4) Directly in field	57·8	2·6	90·5	5·5	56·0	2 Oct 57	81
LSD 0·05	6·92	0·22	8·50	0·58	NS		
0·01	9·51	0·66	11·76	0·80	NS		

Table 4. Comparison of propagation methods for Line-8 Solo papaya as measured by height, diameter, percentage flowering 26 May 1958, percentage of crooked trunks and yield

Treatment	Date of seeding	Av. ht cm 26 May 58	Av. dia. cm 26 May 58	Av lb. of fruit per tree 5 Dec 58*	Percentage flowering 5 Dec 58	Percentage crooked trunks
(1) Transplanted at 12 weeks	7 Oct 57	114·2	6·1	13·5	21·1	52·2
(2) Transplanted at 7 weeks	7 Oct 57	140·0	8·3	27·9	85·1	32·9
(3) Seeded in place	30 Oct 57	135·6	7·6	27·1	51·7	5·5
LSD 0·05		11·14	0·90	7·65		
0·01		15·19	1·23	16·73		

*All fruit larger than 2 in. in diameter harvested 5 Dec 1958.

were left in place for about eight weeks for protection from wind, etc. When removed earlier, growth stopped and the plants died indicating the importance of the protection during winter months.

Missing trees were replaced with Line-8 Solo plants (seeded directly in cans 7 October 1957) at seven weeks of age on 22 November 1957, one month after the original seeding in the field. The remaining transplants were held in the nursery and the second transplanting was made 6 January 1958, when the transplants were three months of age from seed. Growth measurements of the three type plantings were made 26 May 1958, approximately seven months later at flowering. Results set out in *Table 4* indicated differences in growth and yield between transplanting at twelve weeks, and transplanting at seven weeks, or seeding in place. There was no apparent difference between the height or diameter of trees seeded in place and transplanted at seven weeks; however, transplanted trees resulted in 27·4 per cent more trees with crooked trunks than those seeded in place. Later transplanting using 12-week old seedlings resulted in 46·7 per cent more crooked trees than seeding in place and 19·3 per cent more than when transplanting took place at age seven weeks. The plants of the ' 7 week ' transplants flowered earlier, as shown by 85·1 per cent of the trees flowering as compared with only 51·7 per cent for those seeded in place (read 26 May 1958). The smaller, slower growing trees of the ' 12-week-old ' transplants flowered only 21·5 per cent, even though they were the same age as the ' 7 week ' transplants and 3 weeks older than the ' seeded in place ' plants.

The results of the greenhouse studies and three field experiments suggested improper transplanting technique could result in distorted root systems and inferior orchard trees. Seeding directly in place produced earlier flowering, more vigorous trees with more straight trunks than poorly transplanted trees in three experiments. In one experiment correctly transplanted trees were as vigorous and flowered earlier than seeded in place trees, but also had more crooked trunks. Yields were reduced with late transplants but were not affected by transplanting at the correct age.

SUMMARY

Two methods of seedage propagation of papaya were compared in three greenhouse and three field experiments. Seeding directly in containers produced a higher percentage with straight tap root than transplanting. Seeding directly in the field produced fewer curved trunks, more vigorous trees and heavier yields than improper transplanting technique.

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Cacao Virus in Trinidad

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Virus was discovered in Trinidad cacao by Posnette (1944) at the River Estate cacao experimental station of the Imperial College of Tropical Agriculture in November 1943. The subsequent rate of spread of the disease suggested that this outbreak started about 1935 (Kirkpatrick, 1950), but the wide-spread occurrence of virus throughout the Northern Range amongst some of the oldest cacao growing on the island may indicate a much earlier origin.

The virus has not been found in Tobago or any of the other Caribbean islands. Elsewhere in the Americas viruses have been suspected in the Paria peninsula of Venezuela (Posnette and Palma, 1944) and in the Dominican Republic (Ciferri, 1948), but no transmissions were made in Venezuela, and in the Dominican Republic the symptoms may have been confused with a mineral deficiency. A cacao virus causing leaf symptoms similar to those in Trinidad was reported from Ceylon by Pieris (1953), but stem swellings have since been recorded (Pieris and Orrelana, 1958).

The cacao viruses in Trinidad and those in West Africa resemble each other in their mealybug vectors and in causing certain characteristic leaf symptoms. However, the two groups of viruses are probably distinct (Thresh and Tinsley, 1959) and it seems unlikely that virus was inadvertently introduced from West Africa to the West Indies (Kirkpatrick, 1950).

Two symptomologically distinct isolates of virus have been made from Trinidad cacao but it is not clear whether they are of distinct viruses (Posnette, 1944; Kirkpatrick, 1953) or whether they are strains of a single virus as suggested by Baker and Dale (1947a) who referred to strain A (Posnette's 'Red Mottle') and strain B (Posnette's 'Vein Clearing'). Until the crucial protection tests have been carried out to indicate relationships between the strains, the latter usage is to be preferred and has been retained in the present paper.

Both strains A and B are non-persistent, as they can be transmitted by insect vectors very shortly after feeding on the source of infection; the ability to transmit the virus is apparently lost 23 hours after removal of the vector from the source (Kirkpatrick, 1953).

DISTRIBUTION

In 1946 the Cocoa Board of Trinidad and Tobago started a survey of cacao virus diseases in the island. This showed that infection was largely confined to the valleys at the Western end of the Northern Range, with an isolated outbreak at Non Pareil Estate to the east of Sangre Grande (see *Figure 1*). The virus is present as far east as Blanchisseuse, and isolated

outbreaks have been reported at Toco. Strain A was found widely in the Diego Martin and Santa Cruz Valleys; strain B in the Maracas Valley and parts of the Santa Cruz Valley. Both strains were present at Non Pareil Estate.

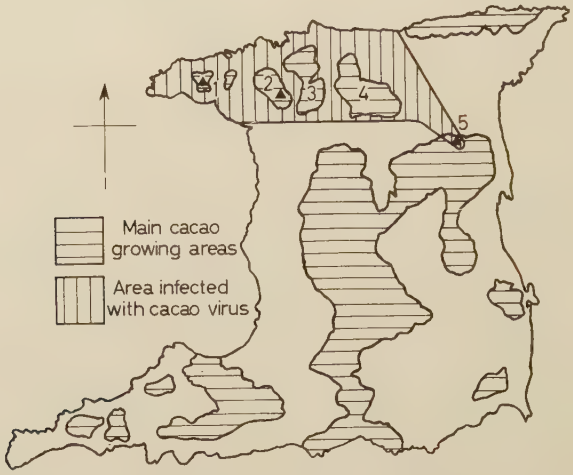

Figure 1. Distribution of cacao virus in Trinidad. 1 River Estate and Diego Martin Valley. 2 La Pastora propagator and Maracas Valley. 3 Santa Cruz Valley. 4 Aripo Valley. 5 Non Pareil Estate

SYMPTOMS AND EFFECTS

The symptoms caused by both virus strains are often inconspicuous, and may be present only on the earliest formed leaves of a flush. Trees which have been infected for a long time may be symptomless carriers of the disease, and strain B tends to mask strain A where both occur together (Baker and Dale, 1947a). Owing to this erratic development of symptoms repeated surveys by trained observers are necessary to find all infected trees.

Strain A symptoms vary from a red vein-banding or interveinal mottle to yellow vein-flecking, being clearest on those trees with unpigmented flushes, and obscured on those which flush dark pink. Red blotches are commonly produced on the yellow pods of certain clones, including ICS 6 and ICS 8.

Strain B symptoms are quite distinct from those described above, being principally a pronounced vein-clearing, often of the finest veins, that persists even after the leaf has matured. Red mottling also appears on the leaves of some clones.

Posnette (1944) recorded leaf crinkle and tip necrosis symptoms with both strains of the virus, but this was not confirmed by Baker and Dale (1947a, 1947b) who thought these effects were caused by poor growing conditions.

The Trinidad cacao viruses are not lethal, but they do impair the growth and yield of trees. Cope (1953) recorded a cumulative loss of yield equivalent to $1\frac{1}{4}$ to 3 pods per tree per year of infection. Taking the lower rate, this would lead to an almost complete loss of crop after 15 to 20 years, assuming

a uniform decline. However, the rate of deterioration decreases 4 to 5 years after infection, by which time one quarter to one third of the crop will have been lost. This would be sufficient to make many of the Trinidad cacao fields uneconomic.

Delayed flushing, early leaf drop, and dieback, leading to a significant loss of condition of the trees and an open canopy, were observed by DALE (1953).

The effects outlined above appear to be independent of the age of the trees. Further work on symptoms and effects is needed.

LATENT PERIOD AND SPREAD OF THE DISEASE

The latent period of the disease in mature cocoa trees is unknown. With beans infected by insects, symptoms appeared about 30 to 50 days after germination (KIRKPATRICK, 1953), and when small seedlings were budded with infected material, it took 34 to 134 days (BAKER and DALE, 1947a). There was no significant difference between strains.

The vectors of both strains of Trinidad virus and of the swollen shoot viruses in West Africa are Pseudococcid mealybugs. *Planococcus citri* Risso is the commonest and most active species and is probably responsible for most of the spread.

Dysmicoccus (*Pseudococcus*) *brevipes* (Ckll.), *Pseudococcus comstocki* Kuw., and *Ferrisiana virgata* (Ckll.) are also vectors (KIRKPATRICK, 1953). The ant–mealybug association found in West Africa (STRICKLAND, 1951) does not occur in Trinidad to any great extent. Spread of the disease is assisted by the movement of pods and clonal material from an infected source.

DALE (1953), studying uninterrupted spread at River Estate, found that over a period of three years the number of infected trees rose from 45 to 242 out of 576 stands in one plot. Most of the spread was from infected trees to their immediate contacts.

CONTROL AND CURE

The Cocoa Board of Trinidad and Tobago is maintaining a cocoa-free belt around the Northern Range to prevent the disease spreading into the rest of the island. As it is so widespread within this area wholesale cutting-out has been abandoned, and the disease is being allowed to spread unchecked. The control policy at Non Pareil Estate in 1958 was to cut out infected trees and their contacts; these are then lopped and sprayed with insecticides.

The La Pastora cacao propagator, situated in the infected area, has been isolated by a mile-wide cacao-free belt, and all planting material is inspected before dispatch.

Attempts at therapy have failed and the author was unsuccessful in attempting to inactivate Trinidad cacao virus strain B by heat treatment of infected budwood. Hot water treatments of up to 40 minutes at 47·5°C, 20 minutes at 50°C, and 8 minutes at 52·5°C failed to inactivate the virus in budwood from infected seedling Trinitario trees. Longer exposures killed the budwood (MURRAY and SWARBRICK, 1960). These results are similar to those previously obtained by Posnette with swollen shoot virus in West Africa (POSNETTE, 1947).

CONCLUSIONS

Trinidad cacao virus is isolated within a relatively small but heavily infected part of the island, with a single treated outbreak elsewhere. This outbreak is on the edge of the main cocoa-producing part of the island, and the present (1958) control policy is merely maintaining the position, without completely eradicating the disease on this estate. A more vigorous cutting-out policy at this one site could eradicate this source of infection and also avoid the possibility of a more virulent mutant strain of the disease arising there, and doing great damage to the cacao industry of the island.

The Trinidad virus does not seem to have lethal strains, but causes a marked loss of vigour, leading to a cumulative and serious loss of crop.

The origin of the disease is obscure, and it seems possible that it has been present but undetected in the island for a long time.

As the disease is so firmly established further research could be carried out upon it in the infected area, possibly leading to a method of control.

SUMMARY

The published work on cacao virus in Trinidad is reviewed. Two strains of the disease are present in the island, that may on further investigation turn out to be separate viruses. There are no close affinities with the swollen shoot complex of West Africa. The disease is confined to the northwest corner of the island. Symptoms, effects and vectors are discussed, and the present control methods mentioned.

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Oecophylla longinoda *Latr. (Formicidae) and Its Association with* Coccus hesperidum *L. (Coccidae) in Northern Nigeria*

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It has been shown that the association of ants and coccids can be of mutual benefit, the ants being assured of a source of food and the coccids being protected from their natural enemies (Kirkpatrick, 1927; Carter, 1935; Strickland, 1947; Way, 1954b). A further example of this is provided by the relationship between *Coccus hesperidum* and *Oecophylla longinoda* on citrus in Northern Nigeria. In this territory *C. hesperidum* is widely distributed on citrus and the following ants have been found in association with it:

Camponotus sericeus Fab.
Camponotus sp. nr. *perisi*
Oecophylla longinoda (Latr.)
Camponotus maculatus Fab.
Camponotus acvapimensis Mayr.
Myrmecaria striata Stitz.
Crematogaster sp.
Crematogaster gambiensis Andre.

The observations reported here, made on the most common ant species in the association, *O. longinoda*, were recorded in a mixed citrus orchard at the Regional Research Station, Samaru, during 1958 and 1959.

INFESTATION OF CITRUS BY *C. hesperidum*

The coccids are usually found on young shoots and leaves, with the result that there is a more uniform distribution on young trees than on older trees, where the coccids tend to be restricted to new growth.

Damage to the tree is caused both by direct feeding of the coccids and by a complex of fungi known as ' sooty moulds ' which grow on the sweet substance excreted by the coccids. These fungi have a smothering effect on the tree.

Populations of *C. hesperidum* reach their peak at the end of the rains and rapidly decline during the early part of the dry season. This population trend is closely correlated with the growth of the tree, since an annual flush of new growth occurs during the rains. Crawlers hatching during the dry season frequently die because they are unable to find suitable food. The

population trend is reflected in the seasonal variation in the number of trees supporting coccid populations (*Figure 1*).

Similar seasonal variation has been observed on citrus in the Middle East (RIVNAY, 1944).

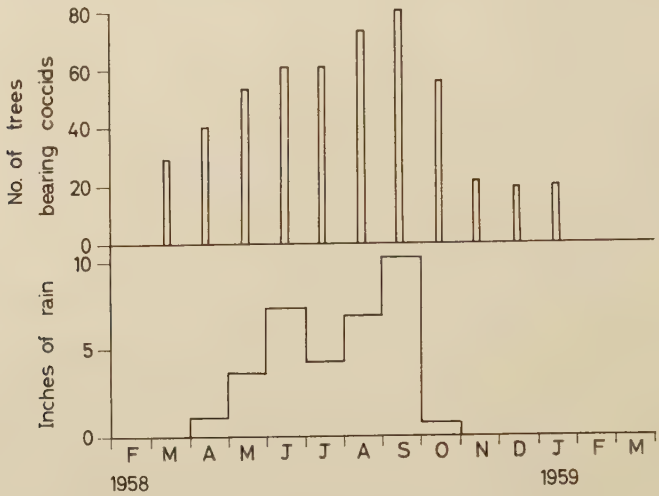

Figure 1. Rainfall and number of citrus trees bearing C. hesperidum, *Samaru 1958–59*

COLONIES OF *O. longinoda* ON CITRUS

O. longinoda is an arboreal species living in colonies comprising several nests. A colony occupies several trees, each tree bearing a variable number of nests. The ants move from tree to tree over well defined paths on the ground, or by overlapping branches. *Figure 2* shows the distribution of colonies in the orchard at Samaru.

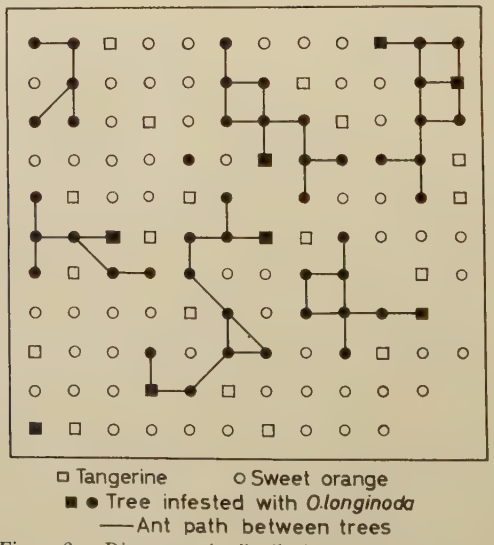

Figure 2. Diagrammatic distribution of colonies of O. longinoda, *Samaru 1958*

Of the two castes of worker the major workers outnumber the minor workers within colonies and usually within nests. The counts in *Table 1* were taken in nests removed from the tree early in the morning when few workers were foraging.

Table 1. Number of workers and immature stages of O. longinoda *in ten nests, Samaru 1958*

Nest No.	*Major workers*	*Minor workers*	*Major pupae*	*Minor pupae*	*Larvae and eggs*
1	663	193	100	6	4
2	1 215	335	81	11	239
3	1 257	761	~ 405	22	661
4	4 176	244	83	22	429
5	387	250	—	—	662
6	3 626	1 104	362	27	723
7	643	507	152	155	187
8	982	459	188	438	188
9	730	199	15	9	17
10	120	58	7	5	3

Immature sexual forms are found in the nests towards the end of the dry season and virgin males and females fly from the nests during the early part of the rains. WAY (1954a) suggested that a colony may produce only one sex at any one time; at Samaru, however, colonies invariably contain both sexes, as do individual nests within the colonies (*Table 2*).

Table 2. Number of male and female O. longinoda *in eight nests, Samaru 1958*

Nest No.	*Males*	*Females*	*Male pupae*	*Female pupae*
1	22	29	40	6
2	30	2	113	13
3	70	25	—	2
4	17	48	180	25
5	162	18	74	—
6	44	55	5	26
7	559	69	3	10
8	46	11	61	153

O. longinoda is common throughout Northern Nigeria although there is a well defined dry season of up to 6 months in the more northerly provinces. The distribution of this species is therefore not as restricted as in East Africa where *O. longinoda* is absent in areas with a similar dry season (WAY, 1954a).

C. hesperidum WITHIN NESTS OF *O. longinoda*

In 395 nests of *O. longinoda* examined, 371 contained colonies of *C. hesperidum*. Over a year the ratio of workers, major and minor, to coccids within nests was approximately 3·5:1. This ratio was very similar during both dry and wet seasons (*Table 3*) even though numbers of coccids exterior to the nest are considerably reduced during the dry season.

Table 3. Number of coccids and number of workers of O. longinoda *in nests in 1958–59*

Season	*No. of nests*	*Total major workers*	*Total minor workers*	*Total coccids*	*Ratio workers: coccids*
Rainy season: May to Oct	115	17 297	12 707	8 868	3·4:1
Dry season: Nov to Apr	120	19 105	14 170	8 973	3·7:1

EFFECT OF *O. longinoda* ON DEGREE OF PARASITISM OF *C. hesperidum*

C. hesperidum is frequently parasitized by *Coccophagus pulvinariae* Compere (Aphelinidae). Counts of *C. hesperidum* within nests of *O. longinoda* and on twigs exterior to the nests examined for the presence of the parasite show that within the nests there is considerable protection to the coccids from parasites (*Table 4*).

Table 4. Effect of nests of O. longinoda *on degree of parasitism of* C. hesperidum

Location	*No. of twigs or nests*	*No. of coccids*	*No. of parasitized coccids*	*Percentage parasitism*	*Overall percentage*
Outside nests of Oecophylla	3	309	95	30·7	16·8
	3	275	12	4·2	
	3	281	66	23·4	
	3	174	37	21·2	
Inside nests of Oecophylla	7	2 174	9	0·4	0·4

C. pulvinariae is very active during the dry season when populations of *C. hesperidum* are low and colonies of the coccid invariably contain many parasitized individuals. During this period, however, coccids within nests of *O. longinoda* show very little parasitism.

It was observed that the adult parasites will move out of the way when workers of *O. longinoda* approach although the ants seem to take little notice of the parasites' presence. This disturbance of the parasites may reduce the rate of parasitism especially within the nest, where its effect would be more pronounced.

EFFECT OF *O. longinoda* ON PREDATORS OF *C. hesperidum*

C. hesperidum on young nursery stock citrus is frequently attacked by predatory Coccinellids, both adults and larvae. Coccinellids, however, are never seen attacking *C. hesperidum* on trees colonized by *O. longinoda*. Any Coccinellids arriving on these trees are driven away or killed. DAS (1959) made similar observations on trees in Ceylon where *C. hesperidum* was free of predators on ant-infested bushes.

CONTROL OF *C. hesperidum* BY EXCLUSION OF *O. longinoda*

Shoots bearing colonies of *C. hesperidum* were grease-banded to prevent access by *O. longinoda*. After one month populations of *C. hesperidum* on these shoots had declined considerably (*Table 5*).

Table 5. Effect of exclusion of O. longinoda *from shoots bearing* C. hesperidum, *Samaru 1958*

Condition		*No. of coccids at start*	*No. of coccids after 1 month*
Oecophylla	(a)	406	275
attending	(b)	13	451
Coccids	(c)	30	96
	(d)	480	375
		929	1 197
Oecophylla	(a)	489	92
excluded	(b)	19	11
from	(c)	45	23
coccids	(d)	520	54
		1 073	180

Colonies of *C. hesperidum* from which *O. longinoda* had been excluded were subjected to heavy parasitism by *C. pulvinariae*. This may be due to lack of any disturbance by workers of *O. longinoda*. In addition a large accumulation of honeydew and sooty mould develops over the coccids; this not only restricts the growth of the colony, but may also reduce the colony due to suffocation of the coccids.

MOVEMENT OF *C. hesperidum* BY *O. longinoda*

When nests of *O. longinoda* are abandoned, very few *C. hesperidum* remain within these nests. Crawlers of the coccid leave the nest to make their way to more favourable positions. In some cases workers of *O. longinoda* were observed carrying nymphs of the coccid to other positions; this transportation of nymphs has been observed both in the field and in the laboratory.

SUMMARY

Coccus hesperidum L. is commonly found on citrus throughout Northern Nigeria. It is invariably associated with several species of ants of which *Oecophylla longinoda* (Latr.) is the predominant species. A close association exists between *O. longinoda* and *C. hesperidum*.

Populations of *C. hesperidum* on citrus reach their peak at the end of the rainy season but rapidly decline during the dry season.

O. longinoda colonies extended over several trees and within the colonies major workers outnumber minor workers. Virgin sexual forms are released at the beginning of the wet season and individual colonies produce both sexes.

Nests of *O. longinoda* frequently contain colonies of *C. hesperidum* and populations of coccids within the nest remain constant throughout the year providing a reservoir of infection.

O. longinoda gives complete protection to *C. hesperidum* from Coccinellid predators and its nests confer a considerable protection to the coccids within from the parasite *Coccophagus pulvinariae* Compere. Exclusion of *O. longinoda* from *C. hesperidum* leads to heavy parasitism and contamination with honeydew with a rapid decline in coccid numbers.

O. longinoda workers transport nymphs of *C. hesperidum* to favourable feeding sites.

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The Effect of Staking and Pruning of Field Grown Indeterminate Tomatoes in Trinidad

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Tomatoes in Trinidad are grown under field conditions during the dry season months from December to May principally by small farmers. Seedlings are transplanted when they are about a month old from field-side nurseries into shallow holes, in which a handful of well rotted and sieved pen manure has been incorporated. From one to three seedlings are set per hole at a row spacing of 3 to 4 ft by 1·5 to 2 ft in the row. They are moulded up two to three times by hand hoeing so that they appear finally to have been planted on ridges rather than on the flat. The only varieties grown are indeterminate in growth habit. No staking or pruning is done and the moulding-up process therefore, in addition to controlling weeds and aerating the surface layers of the soil, assists in basal stabilizing of the plant.

The series of experiments reported here was designed to assess the value of staking and pruning to tomatoes so cultivated.

REVIEW OF LITERATURE

Experimental evidence on the value of pruning and staking tomatoes is conflicting. This is undoubtedly due to the numerous variables encountered, such as length of growing season, light intensity, temperature, rainfall, prevalence of disease, variety, spacing and soil fertility.

Working under temperate conditions in Minnesota, U.S.A., Currence (1941) using both determinate and indeterminate types of tomatoes, found that the total yield of marketable fruit per acre at spacings ranging from 4 ft × 1 ft to 4 ft × 4 ft were considerably reduced by pruning and that staking had little effect on yield. On the other hand staking and pruning generally improved fruit size and had some effect on earliness of fruiting. Similar results have been shown by Thompson (1934) in New York, Magruder (1924) in Ohio, Strydom (1955) in South Africa and Strickland (1934) in Australia.

Deonier *et al.* (1944) in Mississippi, however, made the following comparisons:

(*a*) Staked and pruned at 4 ft × 2 ft
(*b*) Staked and nonpruned at 4 ft × 4 ft
(*c*) Nonstaked and nonpruned at 4 ft × 4 ft

and found that the yields per acre and size of fruit were greatest in the first treatment. Their results, and those of Thompson who also varied his spacing, would have been more valid had the staking and pruning treatments been compared at identical spacings as in the case of Currence.

Information on this aspect of tomato cultivation within the tropics is limited. In Puerto Rico, over two seasons, RIOLLANO (1944), using the indeterminate variety Marglobe at a spacing of 4 ft × 2·5 ft, found that the yield of fruit was reduced significantly by staking and that the combination of staking and pruning caused further reduction. Furthermore, staking significantly lowered the quantity of early fruit set, though the size of fruit was not affected by any treatment. Similar results with regard to the staking of canning tomatoes have been reported by JACKSON (1957) in Kenya.

Work in Trinidad, using results from one crop only, is reported by WIGHT (1933) and by TOPPER (1942). Wight found no significant differences between total yields of staked–pruned and unstaked–unpruned plants set at 4 ft × 2 ft. The latter treatment, however, gave a higher proportion of fruit of exportable quality. Topper, using similar treatments, at spacings of 3 ft × 1 ft, 3 ft × 1·5 ft and 3 ft × 2 ft showed that staked–pruned plants gave greater yields than unstaked–unpruned plants and also tended to give larger fruit size, but with an increase of physiological disorders, such as fruit cracking.

THE EXPERIMENTS

A series of three experiments was laid down during the dry season (December to April) over the years 1957 to 1959 to compare the effects of staking and pruning on a locally selected indeterminate variety. Modern randomized layouts were used in which numbers of plants per plot varied from 42 to 56. This compares with an optimum plot size of 36 plants recommended by Strickland. The three treatments used were:

(*1*) Nonstaked–nonpruned (i.e. traditional)
(*2*) Staked–nonpruned
(*3*) Staked–pruned.

The coefficient of variation per plot in these experiments was 18·5, 11·8 and 10·4 per cent in each of the three respective years.

The crops were grown on the College farm, on a light sandy-silt soil of poor inherent fertility. Seedlings were raised in open nurseries at a spacing of 3 in. × 3 in. and transplanted to the field when a month old, one per hole at a spacing of 3 ft × 1·5 ft. Each plant was given some soluble fertilizer and insecticide in water at transplanting as recommended by CAMPBELL (1958). At from one to two weeks after transplanting the plants were circle-top-dressed with a 5:23:15 mixture containing sulphate of ammonia, 45 per cent superphosphate and sulphate of potash, and at five to seven weeks a second top dressing of a 6:15:23 mixture. The total quantity applied was at the rate of 1 200 lb/acre in two equal amounts. Weeding and moulding were carried out as necessary and irrigation water applied through an overhead irrigation system at a rate equivalent to 1 to 1·5 in. per week when required. Regular weekly sprayings of fungicides and insecticides were made which effectively reduced leaf damage.

In the staking treatments each plant was tied with twine to a bamboo stake 5 to 6 ft high and in the pruning treatments plants were pruned to a single stem by the early removal of axillary shoots. Fruit was harvested when full green or just beginning to turn pink, weighed and graded into two sizes, those with a diameter greater than 2 in. and those with a diameter of less than 2 in.

RESULTS

(1) *Total yield and size of fruit*

Compared with local production, yields during the first two years were very good and in the third year outstanding (*Table 1*). In the first and third years total yields per acre from the staked–nonpruned and nonstaked–nonpruned treatments were significantly better than those in the staked–pruned treatment. In the second year no significant differences were shown between any of the treatments, but yields from the nonstaked–nonpruned plots were adversely affected by the incidence of leaf diseases in the later stages of growth despite regular spraying. Analysis of the results on a three-year basis shows that staking had no effect and that pruning significantly reduced the yield.

Table 1

Treatment	*Total yield of fruit, lb/acre* 1957	1958	1959	3-yr means
Nonstaked–nonpruned	17 307	12 455	44 755	24 839
Staked–nonpruned	18 773	13 526	42 000	24 766
Staked–pruned	10 848	12 604	32 440	18 361

Treatment	*Percentage of total yield in each grade* 1957		1958		1959	
	> 2 in.	< 2 in.	> 2 in.	< 2 in.	> 2 in.	< 2 in.
Nonstaked–nonpruned	54	46	59	41	84	16
Staked–nonpruned	53	47	58	42	81	19
Staked–pruned	46	54	57	43	84	16

With regard to grading of the fruit, the percentage in the two sizes (*Table 1*) is essentially similar in each of the three experiments in the same year. No advantage therefore appears to be gained by staking or pruning but it is noteworthy that the high yield of the 1959 season is reflected in larger fruit size.

(2) *Time of fruiting*

Tomato plants in Trinidad start producing ripe fruit about eight weeks after they are transplanted to the field. Maximum weekly yield is achieved about two to four weeks later and cropping is virtually complete six to eight weeks after first fruiting, that is four and a half to five months after sowing the seed.

The effect of staking and pruning on weekly yields per acre is shown in *Figure 1*. No observable difference in earliness of fruiting between the three treatments could be seen though weekly yields from the staked–pruned treatment fell off markedly from the tenth week, whereas the staked–nonpruned and nonstaked–nonpruned treatments, whose yield curves followed each other very closely, attained their maximum two weeks later.

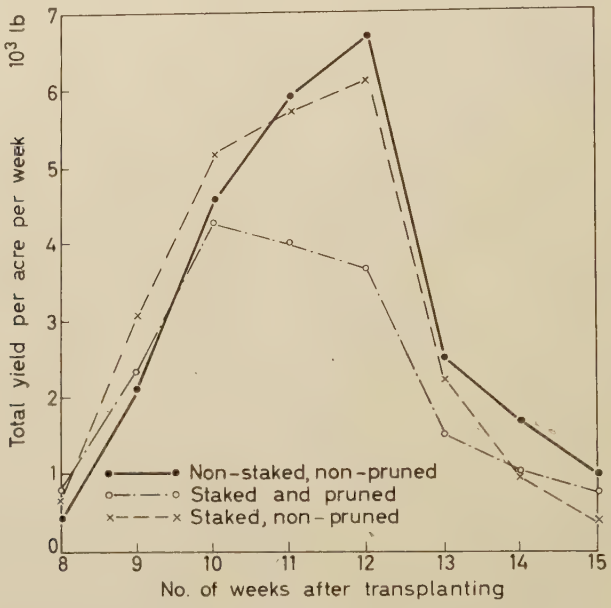

Figure 1. Total weekly yield per acre (3 year average) for each treatment from the eighth week after transplanting

(3) *Costs of production*

Production costs were recorded during the last two experiments (*Table 2*).

Table 2. Cost of production per acre ($1 W.I. equals 4s 2d)

Treatment	*Cost per acre* 1958 $	*Cost per acre* 1959 $	*Percentage increase of costs* 1958	*Percentage increase of costs* 1959	*Mean*
Nonstaked–nonpruned	801·63	1 244·34	100·0	100·0	100·0
Staked–nonpruned	1 267·83	1 632·24	158·2	131·3	144·8
Staked–pruned	1 374·36	1 750·68	171·5	140·6	156·1

These costs are extremely high due to the small plots involved, the care and time necessary in harvesting and subsequent raising of the results to a per-acre basis. However, despite this, it is pertinent to observe that staking increased costs by 45 per cent and pruning by a further 11 per cent and as neither practice increased yields, both are clearly uneconomic.

DISCUSSION

The results obtained in these experiments, with particular reference to total yield per acre, size of fruit and costs of production, have definitely shown that under dry season conditions at a spacing of 3 ft × 1·5 ft using a locally selected indeterminate variety, the most economic method of growing tomatoes is by neither staking nor pruning. These conclusions, together with the evidence from similar experiments conducted elsewhere, would appear to confirm that the local practice in these respects cannot be improved upon. However, as previously reported (CAMPBELL and BHARATH, 1960), other general cultivation practices, such as the production of stronger seedlings, improved varieties, greater use of fertilizers and better control of pests and diseases can be bettered.

In considering the general application of these results a number of other factors must be noted. These experiments have been carried out during the dry season under controlled irrigation. Under wet season conditions, on the other hand, it is almost certain that loss of fruit by rotting from the unstaked–unpruned plots would be excessive and that the microclimate round the plants would favour disease incidence, leading to reduced yields. In this instance therefore, staking may be of value. Again, staking may be necessary, even under dry conditions, where there is the possibility of fruit lying on the ground being infected with soil-borne diseases which cause rotting. This often occurs in certain parts of the West Indies. In either of these cases, it is still doubtful whether pruning is justified.

Currence has shown, furthermore, that conflicting results may occur when different varieties of tomatoes are subjected to staking and pruning. His work has stressed the importance of making comparisons at similar spacings or populations per acre. At higher populations than those already investigated, there will obviously be a point at which staking and pruning will be essential, as for instance in more intensive greenhouse and hydroponic production. Further experimental work is therefore necessary to investigate the effects of spacing and varieties, particularly those having a determinate growth habit, with regard to staking and pruning.

SUMMARY

A series of experiments laid down during the dry season (December to April) over the years 1957–59 to compare the effects of staking and pruning on a locally selected indeterminate variety, at a spacing of 3 ft × 1·5 ft, has shown that the most economic method of production involved neither staking nor pruning. In addition staking and pruning had no favourable effect on size of fruit or earliness of fruiting.

ACKNOWLEDGEMENTS

Thanks are due to Mr R. H. Forster for comments and to Mr W. F. K. Christian for the use of data from his postgraduate report in 1958.

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Book Reviews

THE INDIGENOUS LIVESTOCK OF EASTERN AND SOUTHERN AFRICA

I. L. Mason and J. P. Maule. *Technical Communication 14*, Commonwealth Bureau of Animal Breeding and Genetics: Edinburgh, 1960. *xv* + 151 *pp.* (illus.) 45*s*

Several books have recently been published in which the adjective ' indigenous ' is used to qualify the phrase ' livestock of Africa '. In fact, there are no ' indigenous ' domesticated cattle on the African continent, since all the breeds at present recorded as ' native ' to Africa have made their way, either across the Nile delta or via the Arabian Gulf, from Asia and the Near East.

The reason for the misuse of the adjective is to avoid a discussion of European breeds of domesticated cattle represented in Africa, and to exclude various crosses of European breeds, and of improved Asian breeds, with the cattle of more ancient Asiatic origin. In the opinion of the reviewer, a more helpful approach will be a thorough description of the total cattle population in the various African regions, since the crossbreeding work carried out in recent years is likely to be of prime importance in determining the type of cattle to be seen on the African continent in the future. Unless a description of the improved breeds of cattle recently imported by sea and air is included, future authors of parallel works to the present one will have difficulty in obtaining information on the precise origins of future stabilized crossbreeds. For instance, the importation of Sahiwal bulls into both the African and the European agricultural regions of Kenya is going to have a marked effect on the cattle population of this territory during the next few decades. Information concerning the bulls imported, and the relative performance of their crossbred progeny and back-crosses, is available at the present time, but this may well be lost by the time the history of the evolution of the ' Sahiwal × Small East African Zebu ' comes to be written.

The authors rightly condemn the system of classification of the cattle population of East and Central Africa of Faulkner and Epstein which is based on the ' assumed origin ' of the breed or type in question. On the other hand any system of classification which differentiates the Zebu animal from the Sanga solely on visual anatomical characteristics, such as the size of horn or the type of hump, is subject to similar criticism. In point of fact, there is little to choose between the ultimate outcome of the system of classification employed by Faulkner and Epstein and that employed in the work under review. Both books are eventually forced into the impossible task of comparing and contrasting supposedly different breeds or types of cattle solely on the basis of published descriptions of the cattle by markedly different observers. The net result is a catalogue of names of places and of

tribes, and the reader is at a loss to know whether there is any real or apparent difference between many of the names listed.

It is easy to criticize, but more difficult to make constructive proposals for the improvement of the situation. Some might argue that the publication of a book of this nature is premature, since it is highly probable that an efficient survey of the blood groups of the cattle found in Africa will eventually produce the key to the whole story and will provide evidence for the consanguinity or dissimilarity of different breeds and types without reasonable doubt. On the other hand, with such a dearth of information available on the livestock of Africa, no publication on this subject can be condemned as being ' premature '; indeed it will be more true to say that books of this standard are long overdue! The main point being made by the reviewer is that a dogmatic classification and discussion of the merits and demerits of different systems of classifications is probably not justifiable at the present time.

Certain publications which would have been of value to the authors in compiling this book do not appear to have been used. A case in question, to which attention has already been drawn by the present writer when reviewing previous books on African cattle, is that by MACKINTOSH (1938): ' Some notes on the Abahima and the cattle industry of Ankole ' published by the Uganda Protectorate Government. These little publications, written from time to time by the more active field officers attached to the territorial governments, are a veritable gold mine of information and, often, are of a high standard.

By far the greater part of this book deals with cattle (67 pp compared to 56 pp for all other livestock together). This is no fault of the authors, and merely serves to show the paucity of the literature on the smaller livestock of Africa. The goat population of East and Central Africa in the last year covered by the *F.A.O. Production Year Book for 1959* was 47·8 million, and this important class of farm animal is certainly deserving of more attention than the 11 pages devoted to it in this book. In the last chapter of the book, the authors attempt to stimulate the reader into filling this big gap in the literature. They state: ' We append the few recent reports we have as an incentive for the men on the spot to correct us rather than as a source of information for others '.

The full plate illustrations in this book are of a reasonably good standard and a great deal of attention must have been given towards assembling the photographic material presented. It is no fault of the authors that, in certain instances, the photographic ability of the officers in the field is not up to that of the photographic staff of the popular farming journals such as *The Farmer and Stockbreeder* ! Thus many of the animals pictured in the plates appear to be out of proportion as care has not been taken to ensure that the head and tail regions were equidistant from the camera lens. Photographing animals in true proportion is no easy task, especially when the stock are not used to being handled, and a great service could be done to future scientific publications on livestock in the tropics, if organizations such as the Commonwealth Bureau of Animal Breeding could issue some notes for the guidance of amateur photographers when obtaining pictures of livestock for publication.

In conclusion, it must be stated that this book is by far the best of its kind which has yet been published, and the standard of writing, of type setting, and of general layout is very commendable. The book is highly priced, and for this reason may not be so widely read as it deserves to be. Presumably the reason for the high price is the large number of photographic plates (179 plates occupying 48 pages). It is a pity that a work of this nature could not have received some sort of subsidy from the Colonial Office, in order that it could have more readily found its way on to the bookshelves of animal husbandry and veterinary field officers working for the improvement of the African livestock population.—P.N.W.

BULLETIN OF THE INTERNATIONAL SOCIETY FOR TROPICAL ECOLOGY

Vol. I, Part 1. 40 *pp*. Part 2. *iii* + 116 *pp*.
Edited, printed and published by Dr G. S. Puri, 10 Chatham Lines, Allahabad, India. 1960

The International Society for Tropical Ecology was founded in 1959 ' to promote the study of ecology in (the) tropics and subtropics in the widest sense of the term '. In addition to promoting research in ecology, the Society proposes to arrange excursions, periodical meetings and training courses; to establish a central ecological library and research institutes with attached field stations; to obtain the necessary finance; and to publish books and monographs, as well as a regular *Bulletin*, the first two numbers of which have now appeared. The Executive Committee consists of distinguished botanists from India and elsewhere.

Vol. I, No. 1 was published in January, 1960 and begins with messages sent to the Society by eminent scientists and institutions. Most of the messages stress the overwhelming importance of ecological studies to the improved use of land, particularly in the tropics, a statement with which few people will quarrel. The rest of this first number gives Dr Gupta's presidential address and abstracts of papers read at an inaugural symposium; these deal mainly with Indian ecology.

No. 2, published in July, 1960, gives the texts of papers delivered at the Forest Ecosystem Symposium held during the IX International Botanical Congress at Montreal in 1959. I presume that these will also be published in the *Proceedings* of the Congress. In these papers ecologists from many countries, but mostly outside the tropics, discuss the problem ' can we find a common platform for the different schools of forest type classification '.

The cover of the new *Bulletin* is somewhat puzzling, as it shows a leaf with a pronounced drip-tip, on which is superimposed a number of small sketches, which I presume symbolize plant products, as alongside we read ' plants in the service of man ', and beneath ' promote peace and prosperity by understanding plant and animal behaviour through ecology '.

The standard of production, paper and printing is poor and there are numerous printing errors, particularly in No. 1. *If* the Society can fulfil the objectives which it has set itself, it should serve a useful purpose. I hope that, provided the standard of the *Bulletin* can be improved, it will

attract contributors to send in original articles on plant, animal and human ecology relating to the tropics.

No price is given on the *Bulletin*, but it appears this is included in the annual membership fee of *Rs* 15; *Rs* 20 for institutional membership; plus an admission fee of *Rs* 5. The International Society of Tropical Ecology welcomes membership from all over the world and anyone interested should communicate with Dr G. S. Puri, the General Secretary, at the address given at the head of this review.—J.W.P.

THE ECONOMICS OF IRRIGATION IN DRY CLIMATES

C. Clark. Oxford: Institute for Research in Agricultural Economics, 1960. 31 *pp.* 5*s*

This well-written economic summary should be read by all who are interested in improving crop yields. The conclusions reached by the author are applicable not only to countries which are classified as having ' dry ' climates (in the sense of having a low annual rainfall) but also to areas in the so-called ' wet tropics ' which have periods of dry weather in one part of the year followed by periods with high rainfall.

The author uses a convenient basis for comparing costs in various countries and at various times. This is the amount of goods or services which could have been obtained for one U.S. dollar in 1950. To compare yields from different experiments and at different times, the author has expressed them uniformly in terms of ' grain equivalents '. Other crops which may have been used have had their value converted to the equivalent value of grain, in accordance with the local prices ruling at the time. All units are expressed in the metric form, a system which has very many advantages over cumbersome English units of acres, pounds, etc.

In the preliminary paragraphs, mention is made of Penman's theories of plant water use. ' Water requirements for all crops must be about the same, if they are grown on the same soil and for the same growing season '. A better way of expressing the theory would be ' Under conditions of optimum water supply, the amount transpired is roughly the same for all crops, in similar climates '. The ' potential evapotranspiration ' as this quantity is known, is not a function of soil type, nor of plant species, but only of climate.

The author has shown that the greatest increase in crop yields per unit of irrigation water is in the U.S.A., where yields are already high. In the underdeveloped countries, where irrigation often means additional draught animals, the difference between gross and net yields becomes greater.

Somewhat indigestible tables of figures, however informative, are apt to become dreary reading. Graphs or histograms are nearly always preferable. The author has 17 tables (some occupying two complete pages) and only one histogram. The work would have been greatly improved if there had been 17 histograms and one table.

For non-economists, it might also have been desirable to define such terms as ' Gross marginal return ', etc.—G.W.S.

RAW HIDES AND SKINS

London: The Commonwealth Economic Committee; Her Majesty's Stationery Office, 1960. 64 *pp.* 6*s* 6*d*

This publication is one of a series prepared by the Intelligence Branch of the Commonwealth Economic Committee. It is in the form of a memorandum giving information on the production, utilization and world trade in raw hides and skins. Other supplementary information is given on livestock numbers, import duties and taxes in various countries. As is to be expected in a publication of this sort, it is composed largely of tabulated statistics. The discussion of these data in the text describes the various trends exhibited and usually gives reasons for large fluctuations in production and trade. Also the British Commonwealth data are separately described and contrasted with world trade as a whole.

One surprising feature is that in no case is a reference given for the information produced in the tables. This is of great importance in view of the varying reliability of statistics from different sources.

For those interested in obtaining detailed data for world production and trade in hides and skins this publication will be a very useful source of information.—T.R.H.

FERTILIZER USE

Nutrition and Manuring of Tropical Crops

A. Jacob and H. von Uexküll, translated by C. L. Whittles. Hanover, West Germany: Verlagsgesellschaft für Ackerbau m.b.H, 2nd ed., 1960. 617 *pp.* (illus.)

The appearance of a second edition of this work only two years after the first indicates the general welcome the book has received and the efforts of the authors to keep their material right up to date. References are now included up to December 1959.

The new edition closely follows the pattern of the first and maintains the same high standard. It is divided into three parts, plant nutrients and manures, the manurial requirements of tropical crops and tables of data valuable for those in any capacity using fertilizers and manures.

The book opens with a brief discussion of the role of the nutrient elements in plant growth, visual plant symptoms due to deficiencies or toxicities and common methods of applying nutrients to plants. It then goes on to examine the types of organic and inorganic manures available with their advantages and disadvantages and the principles involved in their intelligent application to the soil. This part of the book alone deserves study, as it condenses principles, practice and up-to-date examples of plant nutrition into some 50 pages.

The second and major section (350 pages) is devoted to an examination of the nutrient requirements of 40 crops or groups of crops grown in the tropics and subtropics, ranging from cereals, through food crops, oil and fibre plants to fruits. All the important commercial crops are treated as well as a wide range of less important plants. The only species which spring

to mind that might have been included in the scope of the book but were not, are yams, pepper and the chief tropical grasses (though alfalfa, lespedeza and kudzu are covered).

The chapter on each individual crop opens with soil preferences and estimates of the removal of nutrients per year from the soil from an average yield. These are frequently backed up by fairly comprehensive data on plant chemical analyses. An examination of the requirements of particular nutrients follows, together with a summary of important fertilizer trials with their results and implications. As wide a range of nutrients as possible is covered but naturally the greatest emphasis is given to nitrogen, phosphate and potash. Where studies have been carried out, the uses of tissue and soil analysis as diagnostic tools are discussed. Finally, the correct methods of nutrient application are examined and a recommended general NPK mixture for the crop is given for use in the absence of local information. The list of references for most crops is generous and a space is left for readers' notes and additions.

The last section of the book consists of useful tables of conversion factors for fertilizers, weights and measures, chemical names and atomic weights of elements, fertilizer and manure composition and recent territorial consumption, removal of nutrients by crops, geochemical and pedological data and characteristics of common leguminous green manure plants.

The work closes with up-to-date general reference lists on plant nutrition, soils and fertilizers. An author index is given. The book is well illustrated by photographs and diagrams and is well bound, though a stiff cover might have been preferable. The English is fairly free from obvious Germanic constructions and misprints are few.

The new edition of *Fertilizer Use* can again be thoroughly recommended to farmers, extension officers, students and research workers, as its discussions of principles are clear, unambiguous and brief, its recommendations for practice definite and, as far as can be judged, usually reasonable and its coverage both in material and references comprehensive.—I.T.T.

LAND, FOOD AND WATER

H. Addison. 2nd ed., Revised and enlarged. London: Chapman and Hall, 1961. *xii* + 284 *pp.* 21*s*

As the author states in his preface, he has tried to modify the treatment of a technical subject in such a way that it would interest general readers; in this he has been successful. The introductory chapters are a simple exposition of rainfall distribution, river flow and the occurrence of deserts, followed by a brief account of the methods of irrigation.

The author then takes the reader on a tour of some of the major reclamation and water control projects of the world, making a point of the manner in which British capital and engineering skill have contributed to many of these projects. The drainage of the English fens is treated in some historical detail and similar descriptive treatment is given to the Zuider Zee project.

The chapters on the Nile waters convey the author's personal interest in the huge pioneering schemes which have brought so much material benefit to Egypt and the Sudan. The section is of current interest, for there

is a short description of the now famous Aswan High Dam project. In the chapters on irrigation schemes in India and the Negev desert in Israel the author brings out vividly the fact that in a number of areas, the engineering problems are much less intractable than the political ones. In the course of his tour round the world the author gives a brief outline of such well known projects as the Snowy River Scheme, the Kariba Dam, the Grand Coulee Dam and the Tennessee Valley Authority. The magnitude of many of the projects is conveyed by descriptions of their size and their cost. Though none of the projects is treated in a detailed fashion there is sufficient information about each one of them to give the reader an understanding of the planning and of the benefits these have brought to the areas. Throughout, the author emphasizes that the drainage and irrigation schemes have followed in the wake of engineering skills. Although the title includes the word ' land ' the land receives little mention as to how the agriculturist played a major role in the success of such schemes as the Sudan Gezira and the Zuider Zee, nor has the author made more than passing reference to the damage which has resulted from excessive salt accumulation in such areas as the Punjab. Without the agronomist to solve the problems of saline soils many of the schemes he mentions would have a short life. This is now recognized by the fact that plans for irrigation schemes are almost always accompanied by an examination of the soils of the area.

The book is written in a very readable style and is well illustrated by diagrams, though one misses the photographs which are usually associated with this type of book.—J.K.C.

Recent Publications

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Memoirs—Economic Series No. 2: Peasant Farming, 1*s*; No. 3: Readings in Small Scale Farming, 5*s*; No. 4: Clip-Card Accounting on the Farm, 8*s* 4*d*

A Notebook of Tropical Agriculture. 6th ed. rev. and enl. 1957. 12*s* 6*d*

Flora of Trinidad and Tobago: Volume I: Ranunculaceae to Araliaceae complete in 8 parts with index, 26*s* 6*d*
Volume II: Part 1, Rubiales, 2*s*; Part 2, Asterales to Primulales, 3*s* 6*d*; Part 3, Ebenales to Polemoniales (in part), 5*s*; Part 4, Polemoniales (in part), 5*s*; Part 5, Scrophulariaceae to Acanthaceae, 5*s*; Part 6, Verbenaceae and Labiatae, 3*s* 1½*d*

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No. 3 St Vincent. 1958, 25*s*
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No. 6 British Guiana. The Rupununi Savannas (continued). The Intermediate Savannas. General Remarks. 1959, 15*s*
No. 7 Jamaica. Parish of Clarendon 1959, 20*s*
No. 8 Jamaica. Parish of St James 1959, 12*s* 6*d*
No. 9 Grenada. 1959, 18*s*
No. 10 Jamaica. Parish of St Mary 1960, 14*s*

These and earlier publications can be obtained from the Library and Publications Department, Faculty of Agriculture, University College of the West Indies, St Augustine, Trinidad

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The following books written by members of the staff have recently been published:

Insect Life in the Tropics, by T. W. Kirkpatrick. Longmans, Green: London. 35*s*

Bananas, by N. W. Simmonds. Longmans, Green: London. 45*s*

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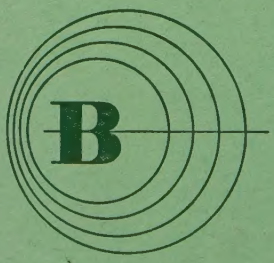
CRICKET, LOVELY CRICKET

In British Guiana sugar and cricket thrive together. Seven years ago a great step forward in co-ordinating the enthusiasm among sugar estate cricketers was made when Clyde Walcott was appointed Cricket Organiser and Coach. Improvements to the amenities already provided were made, and by 1955 nearly all the estates had reasonably good grounds. Cricket in British Guiana has in the past been centred around Georgetown, but organized competitions have been a vital factor in raising cricketing standards throughout the country. Today, cricket on sugar estates and in Georgetown compare favourably, especially in Berbice, which has produced three international stars: Rohan Kanhai, Joe Solomon and Basil Butcher, all of whom come from Port Mourant Estate. The future for estate cricket is bright: several players show great promise, and the standard of the game has improved immensely.



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